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METHANE AND CARBON DIOXIDE EMISSION ESTIMATES FROM U.S. PETROLEUM SOURCES

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Methane and Carbon Dioxide Emission Estimates From U.S. Petroleum Sources

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EXECUTIVE SUMMARY

The United States Environmental Protection Agency (EPA) and others have previously estimated United States emissions of greenhouse gases, including the contribution from the United States petroleum industry. This has led the United States petroleum industry to conduct this more refined estimate of its emissions of carbon dioxide (CO_2) and methane (CH_4) for the base year of 1990 and to project those emissions to the year 2000.

This study consisted of four tasks:

1. Comparison of emission estimation methodologies from published sources;
2. Estimation of year 1990 industry emissions using the Intergovernmental Panel on Climate Change (IPCC) methodology to the extent possible as well as data from other sources as necessary;
3. Selection of a methodology for projecting emissions to the year 2000; and
4. Estimation of emissions for the year 2000.

Tasks 1 and 2 were based upon reviews of existing greenhouse gas inventory literature, and Tasks 3 and 4 were based upon review and use of available published data showing activity and emission projections. Emission estimates for a given time period are calculated by multiplying an emission factor (e.g., units of mass emissions per volume throughput) by an activity rate (e.g., units of volume throughput per time period).

API previously estimated global emissions of carbon dioxide and methane from petroleum sources in reports issued in 1991-1992. This report updates those estimates for the exploration and production, crude transportation, refining, and product transportation segments of the United States petroleum industry. The approach used in this study represents the best available approach for the level of emissions and activity data that is publicly available. This approach is preferable to the United Nation's IPCC methodology for calculating national estimates of greenhouse gas emissions for two reasons:

1) It is specific to the petroleum industry; and
2) It includes some source categories which are omitted in the IPCC methodology.

RESULTS

Existing greenhouse gas emissions literature was reviewed, examining the following key parameters: boundaries, detail level, representativeness, comprehensiveness, data quality, and practicality. None of the existing studies reviewed were found to be ideal for estimating emission rates for the U.S. petroleum industry, but a best estimate approach was developed using the IPCC methodology as a basis with supplemental estimates from the other studies examined. Methods for estimating (year 1990) and projecting (year 2000) activity factors for the petroleum industry were developed based on the literature. Projected changes to emission factors resulting from implementation of proposed regulations as well as energy efficiency improvements were also identified.

Table ES-1 presents the estimated and projected methane and CO_2 emissions from the U.S. petroleum industry. The total year 1990 emissions of CO_2 from petroleum production through product transport are 284 million tons, which compares reasonably well with the estimate in the previous API report of 300 million tons. The differences can be attributed to updated activity factors for the production and transportation industry segments, and to accounting for actual refinery utilization in determining the year 1990 refinery activity factors. The CH_4 emissions of 0.848 million tons for 1990 may be contrasted with an estimate of 0.392 million tons in the previous API study. The difference in the methane estimates can be attributed to the inclusion of production tank emissions and the use of updated activity factors in this study.

Table ES-1. Estimated and Projected Emissions of Greenhouse Gases from the Petroleum Industry (Million Tons per Year).

	Year 1990	Year 2000	Change
Carbon Dioxide	284	288	1.4%
Methane	0.848	0.609	-28%

Total carbon dioxide emissions are projected to increase slightly from 284 million tons in 1990 to 288 million tons in the year 2000. Emissions of CO_2 are projected to decrease in the crude transport segment, but increase slightly in the other industry segments. Projected annual emissions of methane show a reduction of 0.239 million tons over the period. This reduction occurs primarily in the exploration and production segment due to reductions in both the emission factors and the activity factor (amount of crude produced).

The Global Warming Potentials (GWP) recommended by the IPCC and developed by other studies allow scientists to compare the ability of each greenhouse gas to trap heat in the atmosphere relative to other gases. The 100 year GWP for carbon dioxide is 1 and for methane it is 24.5. This means that each ton of methane has about 25 times more global warming impact than a ton of carbon dioxide. When adjusted for GWP, Table ES-2 shows that greenhouse gas emissions (CO_2 and CH_4) from the U.S. petroleum industry will decrease by 0.6% from 1990 to 2000.

Table ES-2. Estimated and Projected GWP-Adjusted Emissions of Greenhouse Gases from the Petroleum Industry (Million Tons per Year).

	GWP	1990 Emissions	1990 GWP Adjusted Emissions	2000 Emissions	2000 GWP Adjusted Emissions	% Change (from 1990 to 2000)
Carbon dioxide	1	284	284	288	288	1.4%
Methane	24.5	0.848	20.8	0.609	14.9	-28%
Total			305		303	-0.6%

SENSITIVITY ANALYSIS

Most of the emission factors used in this study were developed from limited samples of emission measurements. This study's estimate could be further refined in the future if more detailed data become available. No such estimates exist today, although an ongoing study by the U.S. EPA Office of Research and Development (ORD), *"Methane Emissions from the Petroleum Industry,"* may provide that detail for methane in the near future.

General sensitivity examinations were conducted to examine key sources of emissions. For CO_2, the top four emission sources are: drilling, refinery thermal processes, refinery atmospheric separation, and catalytic hydrorefining. The activity factors for these categories are expected to be fairly constant over the ten year period examined in this study, and the emission factors from these sources are known with a reasonable level of certainty. Therefore, the CO_2 estimates in this study do not appear to be very sensitive to the assumptions made.

The general sensitivity examination for methane revealed that the largest single emission source is production tanks and the second largest is production "fugitives, maintenance, and venting & flaring." These two sources dwarf the emission estimates for the other industry segments. Regarding the sensitivity examination:

- The emission estimate is not performed on an equipment level of detail and therefore has some inherent uncertainties.
- The activity factor for these sources is production rate which is somewhat uncertain for the year 2000.
- There is considerable uncertainty as to the absolute level of the methane emission factors for sources in these categories, but it is expected that these factors will remain flat or decline over the period due to measures being undertaken by the industry. As a result, the trend in methane emissions will be flat to declining from 1990-2000.

Therefore, the absolute level of estimates of methane emissions for 1990 and 2000 are more uncertain than the carbon dioxide estimates; nevertheless, the trend in methane emissions is downward from the 1990 levels.

As indicated in Table ES-2, the CO_2 emissions dominate the GWP-adjusted emissions from the U.S. petroleum industry. Therefore, the total estimates of greenhouse gas emissions from the petroleum industry are not likely to be very sensitive to the assumptions made, despite the greater uncertainty in the methane emissions.

CONCLUSIONS

The estimated emissions resulting from this study showed that current estimates of greenhouse gas emissions from the United States petroleum industry are reasonably consistent with previous estimates and that little change is expected in these emissions from 1990 to 2000.

Section 1
INTRODUCTION

The objective of this project is to revise and update the methodology and inventory for methane (CH_4) and carbon dioxide (CO_2) emissions from the United States petroleum industry. API had previously estimated global emissions of methane and carbon dioxide from petroleum sources in reports issued in 1991-1992 (Radian 1991; Radian 1992). This project focuses on emissions from the United States and updates the estimates for the production of crude through the transport of refinery products.

This effort has been divided into four tasks:

Task 1: Comparison of Methodologies—This task compares the attributes of available methodologies and the relative applicability to emissions from the U.S. petroleum industry (see Section 2).

Task 2: 1990 Emission Estimate—To the extent possible, the methodology outlined by the Intergovernmental Panel on Climate Change (IPCC) is used in this task to update the previous methane and carbon dioxide emission estimates for the year 1990 (see Section 3). Data from other sources are used as necessary.

Task 3: Selection of Methodology for Projecting Emissions—This task reviews methods for projecting U.S. petroleum industry emissions to the year 2000 and recommends an approach (see Section 4).

Task 4: Estimation of Emissions for the Year 2000—Based on recommendations outlined in Task 3, this task computes methane and carbon dioxide emission estimates for the year 2000 (see Section 5).

PETROLEUM INDUSTRY BOUNDARY DEFINITION

Boundaries define what is considered the "petroleum industry" and can exclude certain equipment that is not directly related to the petroleum industry. Boundaries must be established for the petroleum industry that are technically reasonable, and that match the boundaries used by other accepted U.S. studies such as the GRI/EPA methane emissions study for the natural gas industry (Radian, 1996).

The petroleum industry can be broken into distinct segments so that data from existing reports can be compared on a consistent basis, and so that segments excluded by certain reports become more readily apparent. Based upon examination of existing emission estimates, the following four segments provide the most consistent approach:

1) Production (exploration/extraction)—This includes all well and surface production equipment, including storage tanks associated with domestic crude production;

2) Crude transportation—This includes all truck, marine, rail, and pipeline transportation of crude, including imported crude;

3) Refining—This includes crude storage tanks, all refinery units, and finished product tanks;

4) Product transportation—This includes all transport of refinery products by truck, marine, rail, and pipelines.

Figure 1-1 shows a simplified conceptual diagram of these industry segments.

Because oil and gas can be produced from the same well, the production segment presents some interesting boundary issues, where some equipment may be related solely to natural gas production, and therefore may not be part of the petroleum industry. Figure 1-2 shows the production sector boundary definitions as defined in the GRI/EPA methane emissions study (Radian, 1996a). The GRI/EPA study of methane emissions from the natural gas industry deals with the production boundary issue on an equipment level detail. Although the GRI/EPA report specified the natural gas industry boundaries, by inference all items outside of the gas industry boundaries are petroleum industry equipment. Experts from API member companies participated in determining

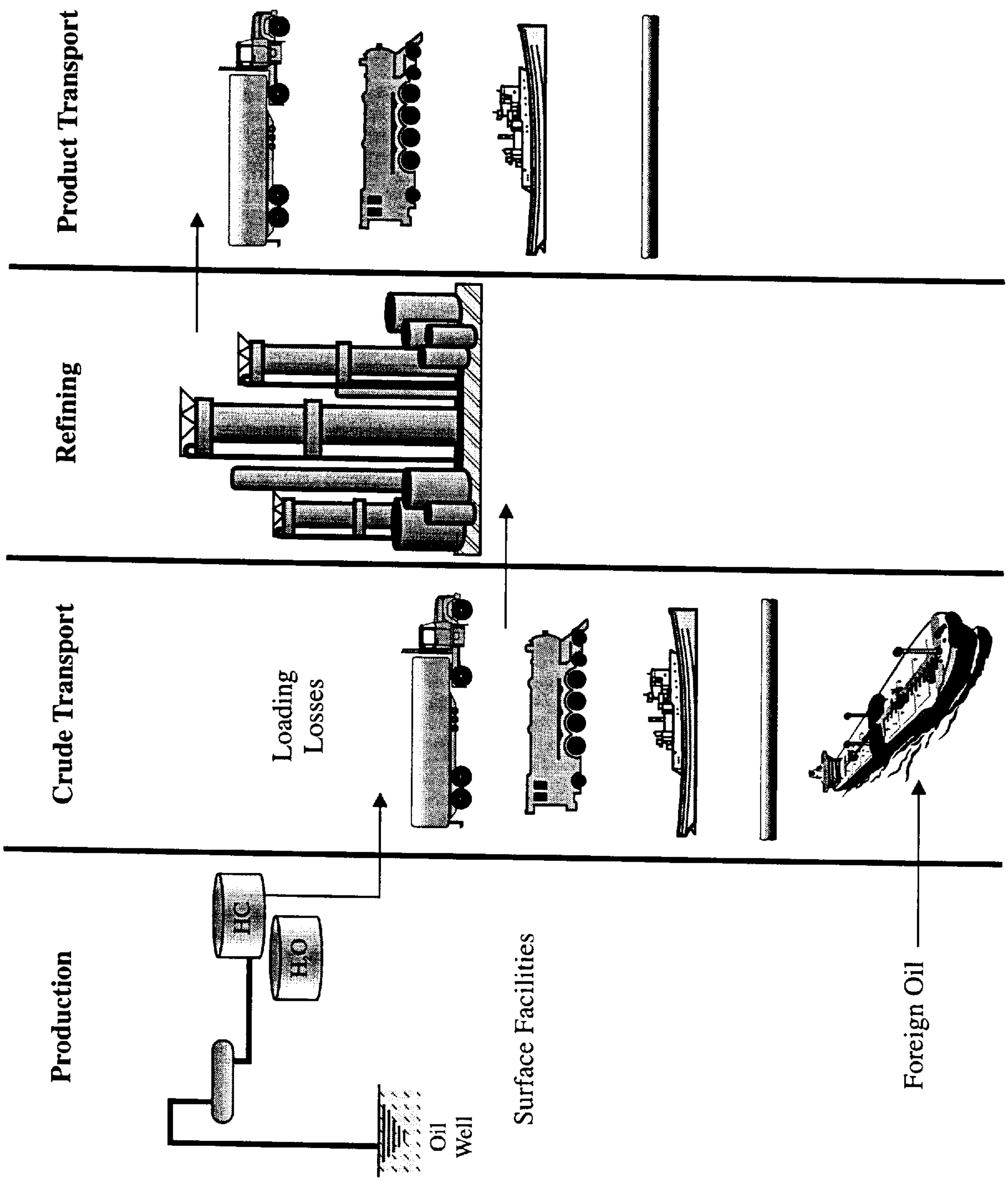

Figure 1-1. Petroleum Industry Segments.

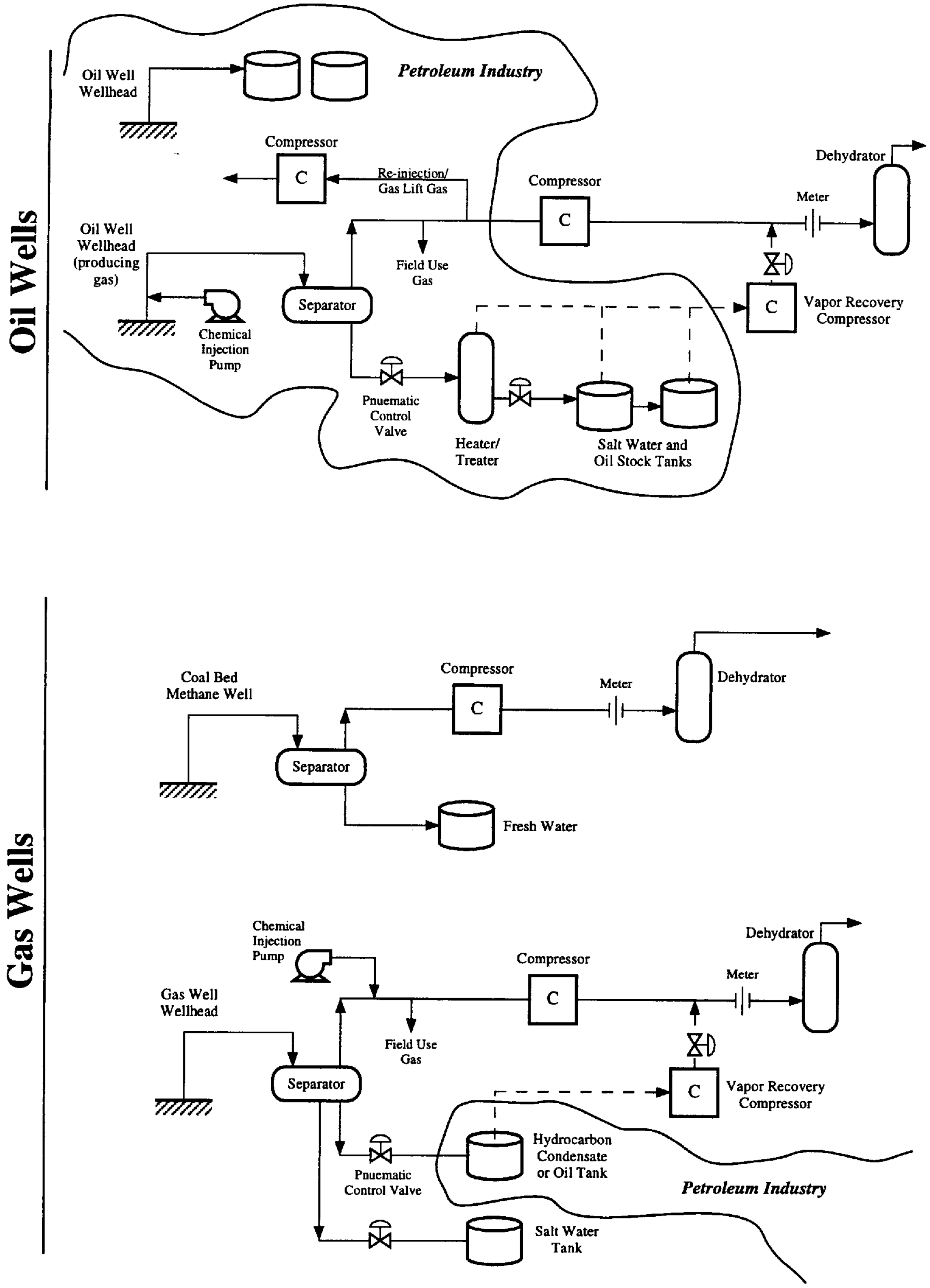

Figure 1-2. Industry Boundaries.

the boundary definition used in the GRI/EPA report. Therefore this report recommends the production boundaries shown in Figure 1-2.

All downstream equipment in crude transportation are included within the petroleum industry boundaries.

Refining includes all refinery equipment and tanks (crude and product tanks). Aromatics and isomerization processes in refineries are also included. However, the refinery boundary excludes the downstream chemical plant operations such as steam cracking ethylene plants, plastic/rubber operations, etc., even though these operations may sometimes be integrated within a refinery complex. The refinery boundaries are consistent with those used by *The Oil and Gas Journal* for reporting refining activities (Thrash, 1991).

Product transport includes all refinery fuel products, but similar to the refining segment, it excludes chemical plant products.

Section 2

COMPARISON OF METHODOLOGIES

The strengths and weaknesses of various recommended methodologies for estimating methane and carbon dioxide emissions from the petroleum industry are compared in this section. This effort centers on the comparison of other, more recent methodologies and inventories to the earlier API reports on greenhouse gas emissions:

API *Global Emissions of Methane from Petroleum Sources* (Radian, 1991).

API *Global Emissions of Carbon Dioxide from Petroleum Sources* (Radian, 1992).

The scope of the methodology comparison was limited to evaluation of the following four sets of reports:

EPA Office of Air and Radiation Reports:

a) *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (EPA, 1994).

b) *Anthropogenic Methane Emissions in the U.S., Report To Congress* (EPA, 1993a).

c) *Options for Reducing Methane Emissions Internationally, Report To Congress*, (EPA, 1993b).

IPCC: *Guidelines for National Greenhouse Gas Inventories*, Volumes 1 through 3 (IPCC, 1995).

E&P Forum: *Methods for Estimating Atmospheric Emissions from E&P Operations* (E&P 1994).

GRI/EPA: *Methane Emissions from the Natural Gas Industry* Multiple reports (Radian, 1996).

In the following portions of this text, the eight reports listed above will be referred by the following names: API CH_4 report, API CO_2 report, EPA Greenhouse report (a), EPA RTC (b,c), IPCC report, E&P Forum report, and GRI/EPA reports, respectively.

STANDARD APPROACH

Most of the reports reviewed calculate total emissions using a standard approach that employs activity factors (AF's) and emission factors (EF's) in the following manner:

$$\text{Emissions} = AF \times EF \qquad \text{Equation (2-1)}$$

where:

Emissions	=	total annual emissions for a specific source reported as a volume or mass per year;
AF	=	activity factor, which is an equipment or unit population or level of activity; and
EF	=	emission factor, which is the emission rate per equipment or emission rate per activity.

The evaluation of methodologies involved examination of both the emission factor and activity factor sources. The sources listed above were reviewed and key elements from each source were compared.

LITERATURE REVIEW

The literature review for this API project was limited to the eight reports listed previously. Some literature search data were available from a concurrent project, however, very few of these sources produced overall methodology data. API directed that the reports listed in the original proposal should be the main focus for this evaluation (API CO_2 report, API CH_4 report, EPA reports, IPCC report, E&P Forum report, and GRI/EPA reports). In a few instances, other reports were evaluated for specific equipment source references; these reports are mentioned in the following sections.

KEY ELEMENT COMPARISON/RANKING

The methodology analysis culminated in a comparison of key elements or parameters. These key elements are: boundaries, detail level, representativeness, comprehensiveness, data quality, and practicality:

1)	Boundaries:	What equipment, especially in the field production area, is included or excluded from the petroleum sector?
2)	Detail Level:	At what level were the emission calculations made (i.e., individual equipment emission factors, or single factors for an entire segment)?
3)	Representativeness:	Were data generated specifically for the U.S. petroleum industry or extrapolated from other industries?
4)	Comprehensiveness:	Did the study include all significant emission sources?
5)	Data Quality :	What was the quality of the data used in the study (i.e., test results or engineering judgement)?
6)	Practicality:	Can the technique be applied by industry, considering current data limitations?

The criteria established for each of these ranking parameters is described in the following subsections.

Boundaries

The boundary (i.e., emission sources relative to the U.S. petroleum industry) adopted by the report being evaluated was compared against the selected API petroleum industry boundary as discussed in Section 1. Most of the reports, with the exception of the GRI/EPA reports, did not estimate emissions on an equipment level so distinct industry boundaries could not be utilized. This is an issue for the production segment particularly, where some of the references report emissions that combine both oil and natural gas industry sources. For example, the IPCC report provides only one methane emission estimate for production, which is based on both oil and gas production activities; no method of separating oil emissions from natural gas is provided.

Detail Level

Detail level refers to the extent at which the calculations were made, such that the more detail involved, the better the approach (more representative of the industry, better quality data, etc.). For example, the E&P Forum report states that calculations can be made in one of five increasingly accurate levels of detail:

Tier 1:	Preliminary regional estimate;
Tier 2:	Emission factor based on fuel consumption and quantity of gas vented and flared;
Tier 3:	Application of emission factors to generic pieces of equipment;
Tier 4:	Application of equipment specific emission factors and operational data such as load variations; and
Tier 5:	Emission data derived from direct measurement.

However, many of these levels of detail are redundant or apply only to a specific site emission estimate, rather than a national estimate. For example, Tier 5 is not possible for a national estimate because it is unrealistic to directly measure emissions from every piece of equipment. Therefore, the Tier 5 approach would have to be combined with Tier 3 to extrapolate measurements from representative pieces of equipment to a national emission estimate.

The following tiers will be used for this API evaluation of the detail level of national estimates:

Tier 1:	Emission data from other reports of unknown quality;
Tier 2:	Approximate industry wide estimates;

Tier 3: Unit/Operation specific emission factors; and

Tier 4: Equipment specific emission factors.

Most reports did not define the detail level at which the values were calculated. However, the detail level can be subjectively determined by review of the report. Table 2-1 shows the emission estimate for each industry segment covered by the reports and the detail level estimated by this analysis. Further breakdown of report detail is discussed in the following sections and shown in Tables 2-2 through 2-11. Please refer to the reports reviewed for details on the sources and calculation techniques used.

Table 2-1. Comparison of Report Detail Levels and Emission Estimates by Industry Segment.

Report(s)	Production		Transportation		Refining		Product Transportation	
	CH_4	CO_2	CH_4	CO_2	CH_4	CO_2	CH_4	CO_2
API CO2		Tier 3 83 MM tons		Tier 3 10 MM tons		Tier 3 197 MM tons		Tier 3 10 MM tons
API CH4	Tier 2 217 k tons		Tier 3 16 k tons		Tier 3,4 97 k tons			
EPA Greenhouse	Tier 2 279 k tons	Tier 2 7 MM tons	Tier 1 7 k tons		Tier 1 13 k tons			
EPA RTC	Tier 2 25 k tons (533) a		Tier 2 7 k tons		Tier 2 14 k tons			
IPCC	b		b		b			
E&P Forum	Tier 1 57 k tons	Tier 1 82 MM tons c	b	b				
GRI/EPA	Tier 4 d							

Notes: Units for carbon dioxide emissions are in million tons carbon dioxide (MM tons) and methane emissions are in thousand tons methane (k tons). Blank cells indicate no estimate.

a Methane emissions for production would be as high as 533,000 tons if the "venting and flaring" emissions estimated by the RTC were included.
b Indicates areas where the report offered emission factors at the unit (Tier 3) or equipment (Tier 4) detail level, but did not provide corresponding activity factors to develop an emission rate estimate.
c Emission estimate based on total production of oil and gas.
d Indicates that the report did not calculate a U.S. inventory for the petroleum industry, but has applicable emission factors.

MM tons = 10^6 tons
k tons = 10^3 tons

Table 2-2. 1990 CO_2 Emissions Summary from API: *Global Emissions of Carbon Dioxide from Petroleum Sources.*

API CO2 Emissions Summary	CO2 EF	CO2 EF units	CO2 AF	AF units	CO2 tons	Subtotal CO2 tons	EF Quality	Emission Factor Basis and Activity Factor Basis (where known)
1. Exploration/Extraction						82,534,246		
Drilling	2887.43	ton/drilled well	27,837	wells drilled	80,377,389		good	combustion equipment (power gen. & other engines)- (Radian, 1989)
Extraction	3.5	ton/well	616,245	active wells	2,156,858		incomplete	combustion equipment (power gen. & other engines)- (Radian, 1989)
Venting & Flaring	0	ton/scf	9.800E+10	cubic ft	0		poor	DOE Energy Information Administration - Venting & Flaring
2. Crude Handling Losses						10,475,509		
Truck Transport	1.1E-05	ton/Bbl mile	1.100E+10	Bbl mile	125,939		good	Fuel type and efficiency , Bbl mile from Transportation in America
Marine Transport	1.3E-06	ton/Bbl mile	2.631E+12	Bbl mile	3,289,250		good	Fuel type and efficiency , Bbl mile from Transportation in America
Rail Transport	6E-06	ton/Bbl mile	5.170E+09	Bbl mile	31,020		good	Fuel type and efficiency , Bbl mile from Transportation in America
Pipeline	3E-06	ton/Bbl mile	2.343E+12	Bbl mile	7,029,300		good	Pump station EF (Radian, 1976) Bbl mile from Transportation in America
3. Refining *						196,843,493		
Flaring	3.7E-05	ton/Bbl	4,951,742,570	Bbl	183,214		unknown	Radian 1980 established tons CO2/barrel total refinery capacity
Equipment Leaks								
-Atm Sep	0.008349	ton/Bbl	4,951,742,570	Bbl	41,339,623		good	Heating req. per unit (Radian, 1980), fuels profile
-Thermal processes	0.082649	ton/Bbl	719,926,000	Bbl	59,500,804		good	Capacity from Oil and Gas Journal
-cat reform	0.00167	ton/Bbl	1,412,721,550	Bbl	2,358,539		good	"
-cat hydrorefining	0.025045	ton/Bbl	880,015,000	Bbl	22,039,976		good	"
-Alkyl	0.030054	ton/Bbl	414,338,875	Bbl	12,452,333		good	"
-Hydrogen	0.018645	ton/Bbl	893,885	Bbl	16,666		good	"
-Vacuum Sep	0.008349	ton/Bbl	2,573,076,625	Bbl	21,481,330		good	"
-Cat cracking	0.008349	ton/Bbl	2,066,982,225	Bbl	17,256,201		good	"
-Cat hydrocraking	0.016697	ton/Bbl	442,631,850	Bbl	7,390,403		good	"
-Cat hydrotreating	0.000626	ton/Bbl	2,604,384,500	Bbl	1,630,605		good	"
-Arom/Isom	0.028384	ton/Bbl	286,858,975	Bbl	8,142,205		good	"
-Lubes	0.01357	ton/Bbl	87,727,750	Bbl	1,190,422		good	"
-Asphalt	0.006345	ton/Bbl	264,863,710	Bbl	1,680,560		good	"
-Cokes	0.006652	ton/Bbl	27,153,445	Bbl	180,611		good	"
Tanks	0	ton/Bbl	4,951,700,000	Bbl	0		-	Not considered a source for CO2
4. Product transport						9,683,752		
Truck Transport	1E-05	ton/Bbl mile	2.365E+11	Bbl mile	2,412,708		good	Average specific gravity of 6 products, fuel type and efficiency
Marine Transport	1.1E-06	ton/Bbl mile	1.100E+12	Bbl mile	1,210,000		good	Bbl mile from Transportation in America
Rail Transport	5.3E-06	ton/Bbl mile	9.048E+10	Bbl mile	479,544		good	"
Pipeline	3.1E-06	ton/Bbl mile	1.830E+12	Bbl mile	5,581,500		good	"
Total						300	10^6 tons CO2	
						5,160	Bscf CO2	

* Note: Previous API report (Radian, 1991) cited 182,538,000 tons CO2 for refining, but this number was based on emission factors (EFs) with one significant figure. When the more detailed EFs are used (more significant figures), the number shown in this table results.

Table 2-3. 1990 CH_4 Emissions Summary from API: *Global Emissions of Methane from Petroleum Sources.*

API CH4 Emissions Summary	CH4 EF	CH4 EF units	CH4 AF	AF units	CH4 tons	Subtotals CH4 tons	EF Quality	Emission Factor Basis and Activity Factor Basis (where known)
1. Exploration/Extraction						217,208		
Drilling	0.052	ton/drilled well	27,837	wells drilled	1,448		unknown	
Extraction *	0.1736	ton/well	616,245	active wells	106,980		very poor	Power generation equipment only, (Radian, 1989)
Venting & Flaring **	1.11E-06	ton/scf	9.8E+10	cubic ft	108,780		very poor	EIA V&F numbers, assumed %F, assumed F efficiency, included in total.
2. Crude Handling Losses						15,543		
Marine Transport	2.55E-06	ton/Bbl	1.57E+09	Bbl	4,001		reasonable	(EPA, 1985) AP-42 avg crude comp, 15% CH4 assumption (Radian 1989), vessel type assumptions
Truck Transport	7.9E-06	ton/Bbl	1.37E+09	Bbl	10,839		reasonable	AF from Transportation in America (Eno, 1992)
Rail Transport	7.9E-06	ton/Bbl	8.90E+07	Bbl	703		reasonable	"
3. Refining						96,523		
Flaring	4E-07	ton/Bbl capacity	5.63E+09	Bbl	2,253		unknown	Radian 1980 (assumed that CH4 = VOC emissions from flares), AF from Oil & Gas Journal
Equipment Leaks	1.64E-05	ton/Bbl capacity	5.63E+09	Bbl	92,106		incomplete	Fugitives only at vacuum & atm pipestills (Radian 1989), AF from Oil & Gas Journal
Tanks	4.37E-07	ton/Bbl throughput	4.95E+09	Bbl	2,164		reasonable	AP-42: Vapor displ. during fill, crude comp., 15% CH4 assumed, Model tk farm w/ float. roof assumed
4. Product Transport	0	ton/Bbl		Bbl	0			Not considered a source for methane emissions
Total						329,274	tons CH4	
						16	Bscf CH4	

* Number of wells was incorrectly reported in 1992 API Methane report as 61,234. The correct value is shown here.
** V&F emissions were reported in the 1992 API report, but not included in industry total.
V&F emissions are included in the total shown here.

Table 2-4. 1990 CO_2 Emissions Summary for EPA: *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1993.*

EPA Inventory of Greenhouse Gas Emissions and Sinks: 1990-1993 CO2 Emissions Summary	CO2 EF	EF units *	CO2 AF	AF units	10^6 tons CO2	Subtotals CO2 10^6 tons	EF Quality	Emission Factor Basis and Activity Factor Basis (where known)
1. Exploration/Extraction						7		
Flared	525	g C/m^3	3.41E+09	m^3	7.2		Poor	EF from Marland and Rotty (1984), AF from EIA 1992 Natural Gas Annual
2. Crude Handling Losses								No emission estimates reported.
3. Refining								"
4. Product Transport								"
Total						7	10^6 tons CO2	
						125	Bscf CO2	

* Flared units of g C/m^3 = grams of Carbon equivalent per cubic meter.

Table 2-5. 1990 CH_4 Emissions Summary for EPA: *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1993.*

EPA Inventory of Greenhouse Gas Emissions and Sinks: 1990-1993 CH4 Emissions Summary	CH4 EF	CH4 EF units *	CH4 AF	AF units	1000 tonnes CH4 (metric tonnes)	Subtotals CH4 tons (US tons)	EF Quality	Emission Factor Basis and Activity Factor Basis (where known)
1. Exploration/Extraction	14.26681	g/GJ			253.0	278,884	incomplete	EPA RTC with some adjustments for V&F. IPCC 1990 Reporting Table
Fugitive	1.255772	g/GJ					incomplete	EPA RTC. IPCC 1990 Reporting Table
Routine Maintenance	0.002816	g/GJ					incomplete	EPA RTC. IPCC 1990 Reporting Table
Venting and Flaring	13.00822	g/GJ					poor	EPA RTC with some adjustments for V&F. IPCC 1990 Reporting Table
2. Crude Handling Losses					6.0	6,614	incomplete	IPCC 1990 Reporting Table
3. Refining-fugitives	0.4	g/GJ			12.0	13,228	incomplete	IPCC 1990 Reporting Table. Emissions from refineries and storage tanks
4. Product Transport						0		Not considered to be a source of methane emissions.
Total						298,726	tons CH4	
						14.2	Bscf CH4	

* Units of g/GJ = grams of CH4 emissions per 10e9 Joules
Units of tonnes (metric tons) = 1000 kg

Table 2-6. 1990 CH_4 Emissions Summary for EPA Report to Congress: *Anthropogenic Methane Emissions in the United States: Estimates for 1990*.

EPA Report to Congress CH4 Emissions Summary	CH4 EF	CH4 EF units	CH4 AF	AF units	CH4 tons	Subtotals CH4 tons	EF Quality	Emission Factor Basis and Activity Factor Basis (where known)
1. Exploration/Extraction*						24,566	incomplete	
Fugitive	72	kg/well	309,155	oil wells not mkting gas	24,514		incomplete	PSI Basis, Wellhead only, seps at oil wells marketing gas ignored
Maintenance	0.15	kg/well	309,155	oil wells not mkting gas	51		incomplete	PSI Basis (Tilkicioglu, 1989)
V&F	4-20%	of V&F total	167,519	million scf	*		very poor	Radian 1991, Barnes&Edmund 1990
2. Crude Handling Losses						6,718	incomplete	
Marine Transport					6,718		reasonable	PSI Basis (Tilkicioglu, 1989)
3. Refining						13,546	incomplete	
Equipment Leaks					0		-	PSI Basis (Tilkicioglu, 1989)
Vents of Waste Gas					11,454		incomplete	PSI Basis (Tilkicioglu, 1989) and (Radian, 1980)
Maintenance					0		-	PSI Basis (Tilkicioglu, 1989)
Tanks					2,093		reasonable	PSI Basis (Tilkicioglu, 1989)
4. Product Transport						0	-	Not considered a source of CH4 emissions
Total						44,830	tons CH4 *	
						2.1	Bscf CH4	

Note:
* Excluded "Venting and Flaring" emissions which were calculated by the RTC to be 101,872 - 508,810 tons CH4

Table 2-7. CH_4 Emissions Summary for IPCC (No Base Year Specified): *Greenhouse Gas Inventory Reference Manual.*

IPCC Greenhouse Gas Inventory - Reference Manual (Vol. 3) CH4 Emission Summary	CH4 EF	CH4 EF units	CH4 AF	AF units	Subtotals CH4	EF Quality	Emission Factor Basis and Activity Factor Basis (where known)
1. Production	7664	kg/PJ prod.				incomplete	US EPA RTC, midpoint determined based on 1/2.4 - 2.4 times.
2. Crude Handling Losses	745	kg/PJ of oil tankered				reasonable	API (1987)
Marine Transport	0.2	g/kg fuel				reasonable	Weaver (1988) - combustion emissions only.
Rail Transport	0.2	g/kg fuel				reasonable	Weaver (1988) - combustion emissions only.
3. Refining	90-1400	kg/PJ refined				incomplete	US EPA-emissions from oil refining
Storage Tanks	20-260	kg/PJ refined				incomplete	US EPA-emissions refining related oil storage tanks
4. Product Transport							No emission factors provided for this segment.
Total						tons CH4 Bscf CH4	

Table 2-8. CO_2 Emissions Summary for IPCC (No Base Year Specified): *Greenhouse Gas Inventory Reference Manual.*

IPCC Greenhouse Gas Inventory - Reference Manual (Vol. 3) CO2 Emission Summary	CO2 EF	CO2 EF units	CO2 AF	AF units	Subtotals CO2	EF Quality	Emission Factor Basis (and Activity Factor Basis where known)
1. Exploration/Extraction							No emission estimates provided for this segment.
2. Crude Handling Losses							"
3. Refining							"
4. Product Transport							"
Total						tons CH4 Bscf CH4	

Table 2-9. CH_4 Emissions Summary for E&P Forum (No Base Year Specified): *Methods for Estimating Atmospheric Emissions from E&P Operations.*

E&P Forum CH4 Emissions Summary	CH4 EF	EF units *	CH4 AF	AF units	Subtotals CH4	EF Quality	Emission Factor Basis and Activity Factor Basis (where known)
Tiers 2 and 3:							
1. Production							
Diesel combustion	0.00014	tonnes/tonne burned				unknown	E&P Forum internal data
Turbines	0.0008	tonnes/tonne burned				unknown	E&P Forum internal data
Engines	0.00014	tonnes/tonne burned				unknown	E&P Forum internal data
Boilers/heaters	7.8E-06	tonnes/tonne burned				unknown	E&P Forum internal data
Gas combustion	0.00042	tonnes/tonne burned				unknown	
Turbines	0.00042	tonnes/tonne burned				unknown	US EPA AP-42 (1986)
Engines	0.017	tonnes/tonne burned				unknown	E&P Forum internal data
Boilers/heaters	4.3E-05	tonnes/tonne burned				unknown	E&P Forum internal data
Flaring							
Gas	0.035	tonnes/tonne burned				unknown	No source listed
Liquid	0.00033	tonnes/tonne burned				unknown	OLF Environmental Programme, "Emissions to Air" (Dec. 1991)
Venting Emissions	0.7	tonnes/tonne vented				unknown	Based on gas composition of 70% CH4
Storage Tanks							
Fixed roof	2E-07	tonnes/tonne throughput				incomplete	US EPA AP-42 (1986), E&P Forum Internal Data
External floating roof	1.5E-07	tonnes/tonne throughput				incomplete	US EPA AP-42 (1986), E&P Forum Internal Data
Internal floating roof	4E-08	tonnes/tonne throughput				incomplete	Laverman, "Evaporation Loss from Storage Tanks," Chicago Bridge and Iron Co. (1991)
2. Transportation							
Air	8.7E-05	tonne/tonne fuel				reasonable	OECD/OCED, IPCC, "Estimation of Greenhouse Gas Emissions and Sinks" (1991)
Sea	0.00027	tonne/tonne fuel				reasonable	Lloyd's Register, "Marine Exhaust Emissions Programme" (1991)
Land	0.00023	tonne/tonne fuel				reasonable	OECD/OCED, IPCC, "Estimation of Greenhouse Gas Emissions and Sinks" (1991)
Crude Loading Operations							
Rail, tank cars, and trucks	5.8E-05	tonne/tonne crude				unknown	E&P Forum Internal Data
Ship loading	1.7E-05	tonne/tonne crude				unknown	E&P Forum Internal Data
3. Refining							Not covered
4. Product Transport							Not covered
Tier 1 Total							
Production, oil	0.000143	tonne/tonne produced	364,292,000	tonnes oil produced	51,984 57,303 2.7	tonnes CH4 tons CH4 Bscf CH4	API "Global Emissions of Methane from Petroeum Sources "(1992)

* tonnes = metric tonne = 1000 kg

Tier 1 Note:

Production, oil and gas	0.00385	tonnes/tonne oil & gas	922,000,000	tonnes oil & gas prod	3,549,700 3,912,869	tonnes CH4 tons CH4	US EPA "Estimation of Greenhouse Gas Emissions and Sinks" (1993)

Table 2-10. CO_2 Emissions Summary for E&P Forum (No Base Year Specified): *Methods for Estimating Atmospheric Emissions from E&P Operations*

E&P Forum CO2 Emissions Summary	CO2 EF	CO2 EF units *	CO2 AF	AF units	Subtotals CO2	EF Quality	Emission Factor Basis and Activity Factor Basis (where known)
Tiers 2 and 3							
1. Production							
Diesel combustion	3.2	tonnes/tonne burned				reasonable	US EPA AP-42 (1986)
Turbines	3.2	tonnes/tonne burned				reasonable	US EPA AP-42 (1986)
Engines	3.2	tonnes/tonne burned				reasonable	US EPA AP-42 (1986)
Boilers/heaters	3.2	tonnes/tonne burned				reasonable	US EPA AP-42 (1986)
Gas combustion	2.75	tonnes/tonne burned				reasonable	US EPA AP-42 (1986)
Flaring							
Gas	2.65	tonnes/tonne burned				unknown	Source not listed
Liquid	3.04	tonnes/tonne burned				unknown	OLF Environmental Programme, "Emissions to Air" (Dec. 1991)
2. Transportation							
Air	3.2	tonnes/tonne fuel				reasonable	OECD/OCED, IPCC, "Estimation of Greenhouse Gas Emissions and Sinks" (1991)
Sea	3.2	tonnes/tonne fuel				reasonable	Lloyd's Register, "Marine Exhaust Emissions Programme" (1991)
Land	3.2	tonnes/tonne fuel				reasonable	OECD/OCED, IPCC, "Estimation of Greenhouse Gas Emissions and Sinks" (1991)
Crude Loading Operations	na						
3. Refining							Not covered
4. Product Transport							Not covered
Tier 1 Total:							
1. Production, oil and gas	0.081	tonnes/tonne oil & gas produced	9.22E+08	tonnes oil & gas produced	74.70	10^6 tonnes CO2	API "Global Emissions of CO2 from Petroleum Sources" (1991)
					82.34	10^6 tons CO2	
					1418.5	Bscf CO2	

* tonnes = metric tonne = 1000 kg

Table 2-11. 1992 CH_4 Emissions Summary for GRI/EPA Study: *Methane Emissions from the Natural Gas Industry (Multiple Reports).*

GRI/EPA Methane Emissions Project CH4 Emissions Summary as applicable to Oil Industry*	CH4 EF	EF units	CH4 AF	AF units	CH4 tons	Subtotals CH4 tons	EF Quality	Emission Factor Basis (and Activity Factor Basis where known)
1. Exploration/Extraction								
A. Fugitives								
oil wellheads (no gas)	17.44	scfd/well	393,235	oil wellheads (no gas)	145			Preliminary data from gas industry - for sites with gas and oil production
oil wellheads (mkting gas)	36.4	scfd/well	208,962	oil wellheads (mkting gas)	161		+/- 24%	Preliminary data from gas industry - for sites with gas and oil production
separators	122	scfd/sep	20,896	separators	54		+/- 33%	Gas industry data. AF based on one separator per well.
sales areas	40.55	scfd/s.a.		oil sales areas	0		+/- 30%	Star Environmental, API Report 4615
pipelines	56.4	scfd/mile	50,000	miles of pipelines	60		+/- 97%	Data from 14 sites
B. Venting								
pneumatics	308	scfd/device		pneumatic devices			+/- 55%	Measurements, site, and manufacturer data, Update 10/95
CIP's	439	scfd/CIP		CIPs			+/- 91%	Measurements, site, and manufacturer data
unmarketed gas (vented)								Sources were considered from gas industry perspective,
H/T vents								but no emission estimate was calculated
oil tanks			600,000	tanks				"
condensate tanks								"
C. Combustion								
gas lift compressors	0.24	scf/HP-hr		Hp-hrs			+/- 5%	TRANSDAT model and SwRI data
gas powered pump engines	0.24	scf/HP-hr		Hp-hrs			+/- 5%	TRANSDAT model and SwRI data
burners								Sources were considered from gas industry perspective,
drilling								but no emission estimate was calculated
D. Maintenance	0.375	scfd/vessel					+/- 67%	Data from 12 sites
E. Upsets								
emergency shutdown	256,888	scfy/platform						Gas industry data
pressure relief valve lift	34	scfy/PRV						Gas industry data
2. Crude Handling Losses	Not covered							Not covered
3. Refining	Not covered							Not covered
4. Product Transport	Not covered							Not covered
Total							tons CH4 Bscf CH4	

Note: * The focus of the GRI/EPA Methane Emissions project was the natural gas Industry. Activity and emission factors were not developed specifically for the oil industry, but some values are applicable to both. Those that were availble are shown here.

Data Quality

Data quality is a function of the detail level (described previously), as well as the basis for the emission factors. Emission factors can be determined from tenuous broad brush estimates, reasonable data-based estimates, or field emission measurements. Tables 2-12 and 2-13 show a matrix of data quality for emission factors and activity factors that range from worst to best. The matrix is based upon a scale of increasing detail level and a scale of better emission/activity factor basis. In these tables "worst" indicates that the emission factor or activity factor estimate is generally applied to the entire industry with poor or incomplete background information to support the estimates. The term "best" indicates that scientifically valid equipment level measurements were performed for the emission factor and the equipment level activity factor is based on a documented nationally tracked source. For both tables, "unknown" indicates that no documentation was provided for a particular emission factor or activity factor, so a ranking could not be estimated.

The matrix scale for data quality was used where possible to subjectively rank the data quality of the emission factor data for each of the reports. The results of this analysis are shown in Tables 2-2 through 2-11. The column labeled “EF Quality” gives a subjective ranking of the data quality based upon the matrix shown in Table 2-12. For the GRI/EPA methane emissions project, 90% confidence bounds for the emission factor terms were calculated to provide an accuracy estimate. These values are listed in the "EF Quality" column for this report.

Data quality also depends on the source for the data. Figure 2-1 shows the approximate lineage for the data for each of the major reports being considered by this analysis. As shown in this diagram, the reports are inter-connected and rely on much of the same information.

Table 2-12. Ranking of EF Data Quality.

EMISSION FACTOR DATA QUALITY		DETAIL LEVEL FOR EMISSION FACTORS		
		Equipment Level	**Refinery Unit Level**	**Entire Industry Segment**
EF BASIS	Measurements	best	good	not applicable
	Field data and calculations	very good	reasonable	not applicable
	Miscellaneous data pulled from other reports	unknown	unknown	unknown
	Estimate	poor	poor	worst

Table 2-13. Ranking of AF Data Quality.

ACTIVITY FACTOR DATA QUALITY		DETAIL LEVEL FOR ACTIVITY FACTORS		
		Equipment Counts	**Refinery Unit Activity Data**	**Entire Industry AF**
AF BASIS	Nationally tracked and reported, well known	best	good	not applicable
	Extrapolated from samples/field data	very good	reasonable	not applicable
	Miscellaneous data pulled from other reports	unknown	unknown	unknown
	Estimate	poor	poor	worst

Equipment Counts (Counts of specific equipment and/or detailed activities)
Refinery Unit Activity Data (based on unit counts and feed rates)
Entire Industry AF (based on total oil produced or refined)

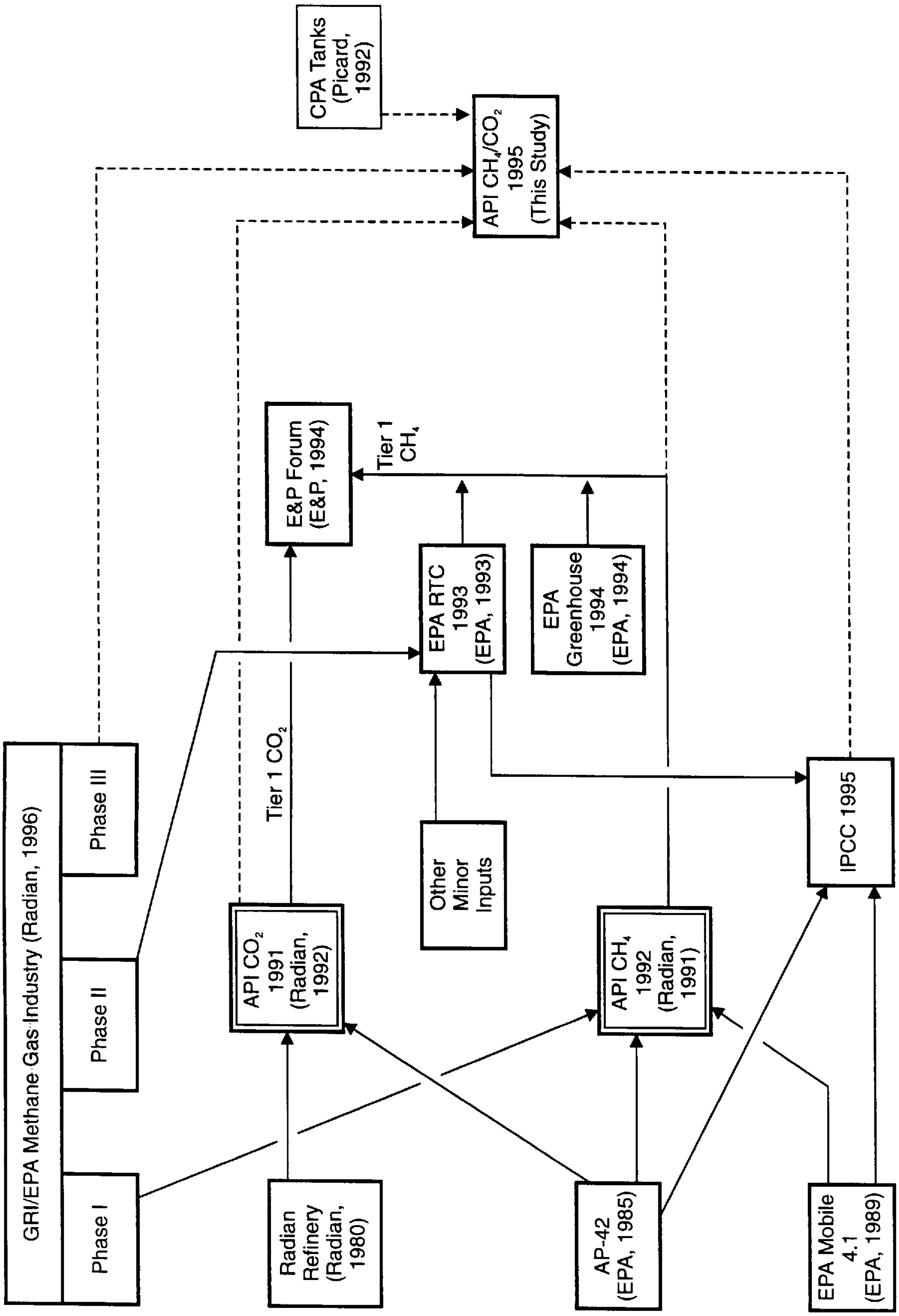

Figure 2-1. Major Flows for Emission Data Lineage.

Representativeness

To the extent possible, representative data are data generated specifically for the United States petroleum industry, rather than extrapolated from other industries or other countries. In addition, data should represent emissions in the United States by accounting for equipment types and operational practices specific to the United States. For example, the activity factor should be based on 1990 production rates and/or equipment populations in the U.S. petroleum industry. Likewise, emission factors should account for regional operating differences and pollution control devices commonly used in 1990.

Unfortunately, most of the reports reviewed did not attempt to account for regional differences in operating practices. The GRI/EPA reports did include these considerations in estimating emissions for the natural gas industry, but the regional differences for oil production may differ. The remaining data sources attempt to make generalizations about emission factors such that they can be applied nationally. The intent of this project is to update emissions presented in the earlier API reports (Radian, 1991; Radian, 1992). Generating emissions based on regional differences, or determining equipment specific emission factors to the level of detail used in the GRI/EPA study, is beyond the scope of this report.

In general, most of the estimates from the reports reviewed are representative, in that they deal with the petroleum industry and are based on emission estimates derived from United States data. For example, the IPCC manual is designed for use by any country, but default emission factors are taken from United States sources. Likewise, the E&P Forum report is published by an international organization and provides emission data from many different countries, but emissions are provided specifically for the United States. The total carbon dioxide emission estimate from the E&P Forum report, however, is based on the production of both oil and gas in the United States. No overall estimate is provided specific to the oil industry in the E&P Forum report.

For the purpose of this API project, the emission estimates must be based on data representative of the United States petroleum industry. An exception is the GRI/EPA reports series which is based on methane emissions from the natural gas industry. Information from the GRI/EPA report is only applicable to the production segment, but in the production segment, equipment and operating practices associated with gas and oil wells are similar and therefore representative of emissions for this study.

The representativeness of individual reports is indicated in Tables 2-14 through 2-18, where "✓" indicates that the emission estimates are developed for the United States petroleum industry.

Comprehensiveness

A comprehensive study should consider all significant emission sources. Even if the detail level is a broad brush approach (Tier 1), it should include an approximation for all significant sources. Tables 2-14 through 2-18 provide an overview of the comprehensiveness. A column in these tables describes any items not covered by the particular report.

Some additional details on comprehensiveness are provided in Tables 2-2 through 2-11, which show industry segments and the individual sources calculated by each report. Any industry segment that is ignored indicates a possible lack of comprehensiveness. Within the segments, equipment that is identified as a major source by one study, but which is ignored by a second study, probably indicates that part of the second study is incomplete.

Comprehensiveness varied from study to study, and varied within studies depending on the segment and the emission (CO_2 or CH_4). In the production segment for CH_4, the GRI/EPA reports had the most comprehensive approach, since these include large emission sources ignored by other reports (pneumatics, chemical injection pumps,

Table 2-14. Total Study Summary Comparison of Representativeness, Comprehensiveness and Practicality.

Reports	Emissions (tons)		Qualitative Ranking		
	CH_4 (10^3 tons)	CO_2 (10^6 tons)	Representativeness	Comprehensiveness	Practicality
API CO_2		2,412	✓	Incomplete	Reasonable
API CH_4	621		✓	1) Ignores major Production segment sources 2) Incomplete Refinery equipment emissions	Oil and Gas industry emissions are combined for production
EPA Greenhouse	542	2,411	✓	1) Ignores major Production segment sources 2) Incomplete Refining emissions	Uses IPCC methodology and providing some 1990 tables submitted to IPCC
EPA RTC	343 (852)[a]		✓	Incomplete emission sources	Only the emission estimate is reported. Difficult to update without knowing EFs and AFs
IPCC	b	b	✓	CO_2 emission factors only provided for end uses	Requires U.S. activity factors in units of Joules
E&P Forum[c]	57	82	✓	Refining and end use segments not included	Requires activity factors for unit and equipment EFs
GRI/EPA[d]	b		✓	CH_4 emissions only provided for production segment	Updating activity factors for production equipment may be difficult

Notes:

a Methane emission rate would be as high as 852,000 tons if the "venting and flaring" emissions estimated by the RTC were included.

b Indicates that the report did not calculate a United States emission inventory, but emission factors were reported.

c E&P Forum report offers Tier 4 emission factors, but only develops a national estimate based upon Tier 1 data. Carbon dioxide emission estimate is based on the production of oil and gas.

d GRI/EPA report is based on production data for the natural gas industry, but is believed to be representative of similar equipment in the petroleum industry.

Table 2-15. Production Segment Comparison of Representativeness, Comprehensiveness and Practicality.

Reports	Emissions (tons)		Qualitative Ranking		
	CH_4 (10^3 tons)	CO_2 (10^6 tons)	Representativeness	Comprehensiveness	Practicality
API CO_2		82.5	✓	Incomplete	Reasonable
API CH_4	217.2		✓	Excluded major Production emission sources due to uncertainty.	Reasonable
EPA Greenhouse	278.9	7.2	✓	Does not include some major Production emission sources.	Uses IPCC methodology and reports some 1990 tables submitted to IPCC
EPA RTC	24.6 (533.4)[a]		✓	Incomplete emission sources	Reasonable
IPCC	b		✓	Based on EPA RTC which does not include some major emission sources. No CO_2 emissions reported for Production	Only emission factors are reported. Requires US activity factors in PJ to calculate emissions.
E&P Forum[c]	57.3	82.3	✓	Reasonable	Requires activity factors for unit and equipment EFs
GRI/EPA[d]	b		✓	Tasks were outside boundary definition	Updating activity factors for production equipment may be difficult.

Notes:

a Methane emission rate would be as high as 533,400 tons if the "venting and flaring" emissions estimated by the RTC were included.
b Indicates that the report did not calculate a United States inventory, but emission factors were reported.
c E&P Forum report offers Tier 4 emission factors, but only develops a national estimate based upon Tier 1 data. The carbon dioxide emission estimate is based on the production of oil and gas.
d GRI/EPA report is based on production data for the natural gas industry, but is believed to be representative of similar equipment in the petroleum industry.

Table 2-16. Crude Transportation Segment Comparison of Representativeness, Comprehensiveness and Practicality.

Reports	Emissions (tons)		Qualitative Ranking		
	CH_4 (10^3 tons)	CO_2 (10^6 tons)	Representativeness	Comprehensiveness	Practicality
API CO_2		10.5	✓	Reasonable	Reasonable
API CH_4	15.5		✓	Reasonable	Reasonable
EPA Greenhouse	6.6		✓	Does not include CO_2 emissions for this segment.	Based on IPCC 1990 reporting tables.
EPA RTC	6.7		✓	Includes only marine transport emissions (ignores emissions from trucks and rail).	Only the emission estimate is reported. Difficult to update without knowing EFs and AFs
IPCC	a		✓	No CO_2 emissions reported for this segment.	Only emission factors are reported. Requires US activity factors in PJ to calculate emissions.
E&P Forum	a	a		Reasonable	Only emission factors are reported. Requires activity factors for unit and equipment EFs
GRI/EPA				Crude transportation is not included in this study.	N/A

Notes:

a Indicates that the report did not calculate a U.S. inventory, but emission factors were reported.

Table 2-17. Refining Segment Comparison of Representativeness, Comprehensiveness and Practicality.

Reports	Emissions (tons)		Qualitative Ranking		
	CH_4 (10^3 tons)	CO_2 (10^6 tons)	Representativeness	Comprehensiveness	Practicality
API CO_2		196.8	✓	Reasonable	Reasonable
API CH_4	96.5		✓	Incomplete refinery equipment emissions	Reasonable
EPA Greenhouse	13.2		✓	Only fugitive CH_4 emissions are provided. Does not include emissions for CO_2 in this segment.	CH_4 AF can only be back-calculated from total emissions and reported EF.
EPA RTC	13.5		✓	Incomplete emission sources	Only the emission estimate is reported. Difficult to update without knowing EFs and AFs
IPCC	a		✓	No CO_2 emissions reported for this segment.	Requires US activity factors in PJ to calculate emissions.
E&P Forum				Refining segment is not included in this study.	N/A
GRI/EPA				Refining segment is not included in this study.	N/A

Notes:

a Indicates that the report did not calculate a U.S. inventory, but emission factors were reported.

Table 2-18. Product Transportation Segment Comparison of Representativeness, Comprehensiveness and Practicality.

Reports	Emissions (tons)		Qualitative Ranking		
	CH_4 (10^3 tons)	CO_2 (10^6 tons)	Representativeness	Comprehensiveness	Practicality
API CO_2		9.7		Reasonable	Reasonable
API CH_4				No emissions reported for this segment.	N/A
EPA Greenhouse				No emissions reported for this segment.	N/A
EPA RTC				No emissions reported for this segment.	N/A
IPCC				No emissions reported for this segment.	N/A
E&P Forum				Product transportation segment is not included in this study.	N/A
GRI/EPA				Product transportation segment is not included in this study.	N/A

compressor fugitives, etc.). However, the GRI/EPA reports are based on the natural gas industry and exclude certain petroleum industry equipment such as tanks. Production tanks can be added in to obtain a more comprehensive equipment basis for the production sector using information from a Canadian study (Picard, 1992).

Practicality

The emission estimate technique must be capable of being applied to the petroleum industry. Certain report approaches define only emission factors, such that activity factor data would have to be compiled to generate an emission estimate. Examples of this are the IPCC report, the GRI/EPA report, and the higher tiers of the E&P Forum report. These reports offer emission factors, but no activity factors and no overall estimate for the United States petroleum industry. Activity factors corresponding to the reported emission factor basis would need to be determined from another source or sources. Reports that already have a current estimate (see Tables 2-14 through 2-18) are the EPA reports, the API CO_2, and CH_4 reports, and the E&P Forum report (for CH_4).

For the reports that require activity factors, the GRI/EPA methane approach is probably the least practical for developing activity factors that correspond to the reported emission factors, since it requires the most detailed activity factor data. However, an evaluation of practicality must be combined with an evaluation of data quality and comprehensiveness, lest a very practical yet completely inaccurate approach is selected.

There are other methodologies that begin to approach the comprehensiveness and practicality of the GRI/EPA methodology, such as the EPA Report to Congress (which was partially based upon Phase 2 of the GRI/EPA reports). The weakness in this method is that the selected approach for CH_4 in the production sector will clearly ignore or underestimate certain sources, based upon the latest data from the GRI/EPA reports. Incidentally, the concurrent ongoing EPA ORD CH_4 emissions study for the

U.S. petroleum industry takes the more detailed route of using the GRI/EPA report basis for the production sector.

A subjective evaluation of the practicality of the reports is listed in Tables 2-14 through 2-18.

CONCLUSIONS

Since this project directed that 1990 emission estimates follow the IPCC basis, some of the gaps identified in the IPCC methodology are outlined below:

For CO_2 :

- The IPCC report only covers emission factors for end uses which are not considered in this study. Other data sources are used to update 1990 emission estimates as discussed in Section 3.

For CH_4 :

- The IPCC report only includes combustion emissions for crude transportation and product transportation. Loading and unloading losses are not built into the United States emission factors.
- In the production and refining segments, only ranges of emission factors are given based on the U.S. EPA Report to Congress (EPA, 1993).
- Venting and flaring emissions in the production segment do not segregate oil from gas wells.

A detailed discussion of the updated 1990 emission estimates, including how these data gaps were accounted for, are provided in the following section.

Section 3

1990 EMISSION ESTIMATE

Section 2 compared carbon dioxide and methane emission estimates from various sources. This section will present updated CO_2 and CH_4 emission estimates for the year 1990. The intent of this study was to update emission estimates based on the IPCC methodology. However, as presented in Tables 2-7 and 2-8, and discussed in Section 2, the IPCC methodology does not provide activity factors, lacks methane emission factors for some major emission sources, and does not provide CO_2 emission factors for the industry segments of interest. The IPCC methodology was used, to the extent possible, to update the 1990 emission estimates. Data from other sources were used to fill in major emission categories.

Tables 3-1 and 3-2 show the updated 1990 emission estimates. In each table, the emission factors and activity factors are provided, with the corresponding units shown. In addition, the data source is listed for both the emission and activity factor of each line item. Details on the determination of these numbers and the calculation techniques used are presented in this section.

METHANE EMISSIONS

As discussed in Section 1, methane emission estimates for the petroleum industry have been divided into four major industry segments:

1. Production (Exploration and Extraction);
2. Crude Petroleum Transportation to Refineries;
3. Refinery Operations; and
4. Petroleum Product Transportation from Refineries.

Methane emission estimates for each industry segment will be discussed in the following subsections.

Table 3-1. API Updated 1990 Emission Estimate for Methane Based on the IPCC Methodology.

API Emission Estimate for CH4 IPCC Methodology 1990 Data	CH4 EF	EF units	CH4 AF	AF units	CH4 tons	Subtotals CH4 tons
1. Production						823,609
Fugitives, Maint., V&F	7664	kg/PJ prod.	7,355,000	bbl/d	138,667	
Tanks	12.1	scf/bbl	7,355,000	bbl/d	684,942	
2. Crude Handling Losses						11,192
Marine Transport	745	kg/PJ oil trans.	299.3	10^6 tons	9,523	
Truck Transport	1.02E-05	t/bbl	24.6	10^6 tons	1,596	
Rail Transport	1.02E-05	t/bbl	1.12	10^6 tons	73	
Pipeline	0	t/bbl	611.6	10^6 tons	0	
3. Refining						13,845
Refinery Operations	355	kg/PJ refined	13,404,791	bbl/d	11,706	
Tanks	4.37E-07	t/Bbl throughput	13,404,791	bbl/d	2,138	
4. Product Transport	0	t/bbl	1,087	10^6 tons	0	0
Total, tons CH4						848,645
Total, Bscf CH4						40

API Emission Estimate for CH4 IPCC Methodology 1990 Data	Emission Factor Sources
1. Production	
Fugitives, Maint., V&F	US EPA RTC combined oil emissions, midpoint determined based on 1/2.4 - 2.4 times (IPCC, 1995).
Tanks	Calculated from CPA data (Picard, 1992)
2. Crude Handling Losses	
Marine Transport	(IPCC, 1995)
Truck Transport	AP-42 (EPA, 1995)
Rail Transport	AP-42 (EPA, 1995)
Pipeline	(Tilkicioglu, 1989)
3. Refining	
Refinery Operations	(IPCC, 1995) Based on range from US EPA-emissions from oil refining
Tanks	AP-42 crude comp, Vapor displ. during fill, 15% CH4, model tank farm w/ float roof (Radian, 1992)
4. Product Transport	AP-42: Not considered a source for methane emissions. (EPA, 1995)

API Emission Estimate for CH4 IPCC Methodology 1990 Data	Activity Factor Basis
1. Production	
Fugitives, Maint., V&F	EIA Petroleum Supply Annual 1990, Volume 1(EIA, 1991)
Tanks	EIA Petroleum Supply Annual 1990, Volume 1(EIA, 1991)
2. Crude Handling Losses	
Marine Transport	Transportation in America, Supplements, Updates & Corrections (Eno, 1992)
Truck Transport	Transportation in America, Supplements, Updates & Corrections (Eno, 1992)
Rail Transport	Transportation in America, Supplements, Updates & Corrections (Eno, 1992)
Pipeline	Transportation in America, Supplements, Updates & Corrections (Eno, 1992)
3. Refining	
Refinery Operations	Oil and Gas Journal based on stream-day capacity and adjusted for util. (Beck, 1995; Thrash, 1991)
Tanks	Oil and Gas Journal based on stream-day capacity and adjusted for util. (Beck, 1995; Thrash, 1991)
4. Product Transport	Transportation in America, Supplements, Updates & Corrections (Eno, 1992)

Table 3-2. API Updated 1990 Emission Estimate for Carbon Dioxide Based on the IPCC Methodology.

API Emission Estimate for CO2 IPCC Methodology 1990 Data	CO2 EF	EF units	CO2 AF	AF units	CO2 Emissions 10^6 tons/yr	Subtotals CO2 MMton/y
1. Exploration/Extraction						95.16
Drilling	2887.4	ton CO2/well	30,200	wells drilled	87.20	
Extraction	1.2	ton CO2/well	602,439	active wells	0.72	
Flared	525	g C/m^3	3.4088E+09	m^3	7.23	
2. Crude Handling Losses						8.87
Truck Transport	1.1E-05	ton CO2/Bbl mile	9.500E+09	Bbl mile	0.11	
Marine Transport	1.3E-06	ton CO2/Bbl mile	1.904E+12	Bbl mile	2.38	
Rail Transport	6E-06	ton CO2/Bbl mile	3.200E+09	Bbl mile	0.02	
Pipeline	3E-06	ton CO2/Bbl mile	2.121E+12	Bbl mile	6.36	
3. Refining						171.24
Flaring	3.7E-05	ton CO2/Bbl	4.893E+09	Bbl	0.18	
-Atm Sep	0.008349	ton CO2/Bbl	4.893E+09	Bbl	40.85	
-Thermal processes	0.082649	ton CO2/Bbl	6.053E+08	Bbl	50.02	
-Cat reforming	0.00167	ton CO2/Bbl	1.171E+09	Bbl	1.95	
-Cat hydrorefining	0.025045	ton CO2/Bbl	7.343E+08	Bbl	18.39	
-Alkylation/Polymerization	0.030054	ton CO2/Bbl	3.499E+08	Bbl	10.52	
-Hydrogen	0.018645	ton CO2/MMcf	7.435E+05	MMcfd	0.01	
-Vacuum Sep/Dist	0.008349	ton CO2/Bbl	2.121E+09	Bbl	17.70	
-Cat cracking	0.008349	ton CO2/Bbl	1.713E+09	Bbl	14.30	
-Cat hydrocraking	0.016697	ton CO2/Bbl	3.784E+08	Bbl	6.32	
-Cat hydrotreating	0.000626	ton CO2/Bbl	2.182E+09	Bbl	1.37	
-Arom/Isom	0.028384	ton CO2/Bbl	2.510E+08	Bbl	7.12	
-Lubes	0.01357	ton CO2/Bbl	6.743E+07	Bbl	0.91	
-Asphalt	0.006345	ton CO2/Bbl	2.247E+08	Bbl	1.43	
-Cokes	0.006652	ton CO2/ton	2.324E+07	t/d	0.15	
Tanks	0	ton CO2/Bbl	4.893E+09	Bbl	0.00	
4. Product Transport						8.77
Truck Transport	1E-05	ton CO2/Bbl mile	1.921E+11	Bbl mile	1.96	
Marine Transport	1.1E-06	ton CO2/Bbl mile	1.051E+12	Bbl mile	1.16	
Rail Transport	5.3E-06	ton CO2/Bbl mile	9.060E+10	Bbl mile	0.48	
Pipeline	3.1E-06	ton CO2/Bbl mile	1.698E+12	Bbl mile	5.18	
Total, MMtons CO2						284
Total, Bscf CO2						4,898

Table 3-2. API Updated 1990 Emission Estimate for Carbon Dioxide Based on the IPCC Methodology (Continued).

API Emission Estimate for CO2 IPCC Methodology 1990 Data	Emission Factor Sources
1. Exploration/Extraction	
Drilling	(Radian, 1991) Combustion equipment (power gen. & other engines)
Extraction	(Radian, 1991) Combustion equipment (power gen. & other engines)
Flared	(EPA, 1994)
2. Crude Handling Losses	
Truck Transport	(Radian, 1991) Fuel type and efficiency
Marine Transport	(Radian, 1991) Fuel type and efficiency
Rail Transport	(Radian, 1991) Fuel type and efficiency
Pipeline	(Radian, 1991) Pump station EF
3. Refining	
Flaring	(Radian, 1991) established tons CO2/barrel capacity
-Atm Sep	(Radian, 1991) Heating req. per unit, fuels profile
-Thermal processes	"
-Cat reforming	"
-Cat hydrorefining	"
-Alkylation/Polymerization	"
-Hydrogen	"
-Vacuum Sep/Dist	"
-Cat cracking	"
-Cat hydrocraking	"
-Cat hydrotreating	"
-Arom/Isom	"
-Lubes	"
-Asphalt	"
-Cokes	"
Tanks	(Radian, 1991) Not considered a source for CO2
4. Product Transport	
Truck Transport	(Radian, 1991) Average specific gravity of 6 products, fuel type and efficiency
Marine Transport	(Radian, 1991) Average specific gravity of 6 products, fuel type and efficiency
Rail Transport	(Radian, 1991) Average specific gravity of 6 products, fuel type and efficiency
Pipeline	(Radian, 1991) Average specific gravity of 6 products, fuel type and efficiency

Table 3-2. API Updated 1990 Emission Estimate for Carbon Dioxide Based on the IPCC Methodology (Continued).

API Emission Estimate for CO2 IPCC Methodology 1990 Data	Activity Factor Sources
1. Exploration/Extraction	
Drilling	(DRI/McGraw Hill, 1993) "Impact of Possible Global Climate Change Policies"
Extraction	(World Oil, February 1992) 1990 Total oil wells
Flared	(EIA, 1993) Natural Gas Annual
2. Crude Handling Losses	
Truck Transport	Transportation in America, Supplements, Updates & Corrections (Eno, 1992)
Marine Transport	Transportation in America, Supplements, Updates & Corrections (Eno, 1992)
Rail Transport	Transportation in America, Supplements, Updates & Corrections (Eno, 1992)
Pipeline	Transportation in America, Supplements, Updates & Corrections (Eno, 1992)
3. Refining	
Flaring	Oil & Gas Journal (Mar 18, 1991) Annual Refining Survey as of 1/1/91
-Atm Sep	Based on calendar-day capacity and
-Thermal processes	Adjusted for 86.6% utilization from EIA Petroleum Supply Annual (EIA, 1991)
-Cat reforming	"
-Cat hydrorefining	"
-Alkylation/Polymerization	"
-Hydrogen	"
-Vacuum Sep/Dist	"
-Cat cracking	"
-Cat hydrocraking	"
-Cat hydrotreating	"
-Arom/Isom	"
-Lubes	"
-Asphalt	"
-Cokes	"
Tanks	"
4. Product Transport	
Truck Transport	Transportation in America, Supplements, Updates & Corrections (Eno, 1992)
Marine Transport	Transportation in America, Supplements, Updates & Corrections (Eno, 1992)
Rail Transport	Transportation in America, Supplements, Updates & Corrections (Eno, 1992)
Pipeline	Transportation in America, Supplements, Updates & Corrections (Eno, 1992)

Production

The IPCC Greenhouse Gas Inventory Reference Manual (Volume 3) provides a range of emissions attributed to oil production (290 - 4,670 kg/PJ of oil produced). This range is taken from the U.S. EPA Report to Congress and consists of emissions from non-gas producing oil wells, including fugitive and maintenance emissions (EPA, 1993). A second range is provided for venting and flaring emissions from oil and gas production (2,870 - 13,920 kg/PJ of oil and gas produced). Unfortunately, data are not provided for splitting oil related venting and flaring emissions from the total. For the purpose of this estimate, it should be noted that some amount of emissions related to gas wells is included in the production emission factor. The combined emission factor range is 3,160 - 18,590 kg/PJ of oil produced.

The Report to Congress presents emissions in ranges to account for uncertainty. The range is asymmetric, such that the mean falls between the minimum and maximum values of the range, but is not an average of the minimum and maximum. The mean for a given range can be determined by the following equations:

$$\text{Minimum} = \frac{\text{Mean}}{\text{UF}} \qquad \text{(Equation 3-1)}$$

$$\text{Maximum} = \text{UF} \times \text{Mean} \qquad \text{(Equation 3-2)}$$

where UF is the uncertainty factor for a particular emission category. Knowing the minimum and maximum values from the range provided, the equations can be solved for the uncertainty factor and the mean value. In this case, the mean is 7,664 kg/PJ oil and the uncertainty factor is 2.42.

The IPCC emission factor range does not include tank emissions, which are believed to be the largest emission source for oil production. Production facilities are generally equipped with tanks for temporary storage of the produced hydrocarbon liquids. The majority of these tanks vent to the atmosphere. Due to the pressure differential between the well and atmospheric pressure, or from a separator to atmospheric pressure, a certain amount of methane is flashed off in the tanks. In addition, breathing and working losses occur as tanks are filled and unloaded. The Canadian Petroleum Association measured "actual" emissions from five production storage tanks at four oil batteries in Canada (Picard, 1992). An emission factor of 12.1 scf CH_4/barrel of oil produced was determined from this study.

The activity factor for production methane emissions is based on the total volume of oil produced: 7,355,000 bbl/d, for 1990 (EIA, 1991). To convert between the energy units used by IPCC (kg/PJ) to barrels of oil, a heat equivalent conversion factor of 5.8 million BTU/barrel crude was used (EPA, 1994).

Crude Transportation

IPCC reports a crude transportation loss emission factor of 745 kg/PJ of oil tankard and references an API report on emissions from marine vessel transfers (API, 1981). Methane losses from truck and rail transportation were determined from Total Organic Compound (TOC) emissions reported in AP-42 as 2 to 5 lb TOC/1000 gallons transferred (EPA, 1995). Assuming a methane composition of 15 wt% and using the median from the reported range, methane emissions from truck and rail loading operations are approximately 1.02 10^{-5} tons CH_4/barrel. Methane emissions from pipeline transportation of crude are considered negligible and are therefore not estimated (Tilkicioglu, 1989).

Crude transportation for 1990 is reported in tons by mode of transport (i.e., water, rail, truck, and pipeline) (Eno, 1991). The heat equivalent conversion factor of 42.71 10^{12} J/1000 tonnes (metric tonnes = 1000 kg) oil was used to convert the marine emission factor to tons (U.S. tons = 2000 lb) of oil (IPCC, 1995). A density of crude is required to convert between barrels and tons. This was determined by the ratio of heat equivalent conversion factors from IPCC (42.27 10^{12} J/1000 tonnes) and EPA (5.8 million BTU/bbl), resulting in a crude density of 7.51 lb/gal.

Refining

IPCC reports a refinery emission factor range of 90 to 1,400 kg/PJ of oil refined. EPA's Report to Congress is the reference for this range, which is based on methane emissions from atmospheric distillation and waste gas streams, primarily heater flue gas (EPA, 1993). The mean and uncertainty factor of this range, determined using Equations 3-1 and 3-2, are 355 kg/PJ and 3.94, respectively. This emission factor was converted from energy units to mass per unit volume based on the heat equivalent conversion factor for crude of 5.8 million BTU/barrel (EPA, 1994).

The previous API report on methane emissions from petroleum sources, included an estimate for methane emissions from tanks of 4.37 10^{-7} tons CH_4/barrel throughput (Radian, 1992). This value was determined based on the vapor displaced during filling from AP-42, using the AP-42 crude composition for a model tank farm with floating roof tanks and assuming 15 wt% methane in the vapor phase (EPA, 1995; Radian, 1992).

The activity factor for refining is based on the 1990 refinery throughout. The calendar-day capacity is reported by the *Oil and Gas Journal* as 15,478,949 barrel/day (Thrash, 1991). This is the maximum capacity of refineries accounting for a predetermined number of days in which units are down for maintenance activities. The 1990 refinery utilization of 86.6%, reported in the Energy Information Administration's (EIA) *Petroleum Supply Annual*, was used to adjust the calendar-day capacity to the actual refinery throughput of 13,404,770 barrels/day (EIA, 1991). This activity factor was applied to both refinery emission factors for methane.

Product Transport

Refined petroleum products contain very little methane (< 1% of the total hydrocarbon emissions are methane) (EPA, 1995). AP-42 reports organic emission factors for loading petroleum products into rail cars and tank trucks, but only gasoline has significant emissions (5-12 lb total organics/1000 gallons transferred) and the methane composition of gasoline is negligible (EPA, 1995). Therefore, for the purpose of this study, methane emissions from product transportation are considered to be negligible.

CARBON DIOXIDE EMISSIONS

The IPCC methodology for estimating carbon dioxide emissions is based on the carbon content of fuel combustion, where CO_2 emissions from energy sources can be estimated from widely available data on commercial fuels. This method, although accurate for a national emissions inventory, does not provide the level of detail necessary to evaluate specific emission sources for the petroleum industry (i.e., comparing production emissions to refinery emissions). Therefore, a more detailed breakdown of carbon dioxide emissions by industry segment is presented in Table 3-2 and discussed in the following subsections.

Emissions calculated from the product of emission factors (EF) and activity factors (AF) were based on EFs reported in the previous API study (Radian, 1991) and AFs from reported 1990 sources. Emission factors and activity factors for each industry segment are discussed in the following sections.

Production

Consistent with the previous API report on carbon dioxide emissions from petroleum sources, production CO_2 emissions are based on three sources: drilling, extraction, and flaring (Radian, 1991). Emission factors for well activities are based on the fuel required to operate drilling and extraction equipment. Activity factors for the number of wells drilled and the number of active wells for 1990 are based on figures reported by API and World Oil, respectively (DRI, 1993; World Oil, 1994). Emissions from flaring are based on an emission factor reported by EPA (EPA, 1994) and the volume of gas flared (EIA, 1993), assuming an 80:20 split between the volume of gas flared versus the volume of gas vented.

Crude Transportation

Carbon dioxide emissions result from engine combustion by the vehicles used to transport crude. The previous API report determined transfer vehicle emissions for marine vessels, tank trucks and rail cars based on the type of fuel, the combustion efficiency, and the quantity of fuel consumed over a 1-mile distance at full load (reported in barrel-miles) (Radian, 1991).

For crude transported via pipelines, CO_2 emissions result from the combustion of diesel to power pump stations. An emission factor (barrel-miles) was calculated based on pump efficiency, utility data, and crude throughput (Radian, 1991).

Activity factors for these four sources are reported as ton-miles of crude transported (Eno, 1991). Ton-miles were converted to bbl-miles using the crude density of 7.51 lb/gal based on heat equivalent conversion factors of 42.71e-12 J/1000 metric tonnes and 5.8 million BTU/bbl (IPCC 1995; EPA, 1994).

Refining

Petroleum refinery operations that result in carbon dioxide emissions include refinery flaring and exhausts from process heaters and boilers. CO_2 emissions per throughput for each refinery process unit were determined from the unit heating requirement and the type of fuels used (Radian, 1991). Flaring emissions were estimated from a typical fuel profile based on the composition of the waste gas stream controlled by flares and a flaring efficiency of 98% (Radian, 1991).

Activity factors are based on the capacity through each refinery process unit and adjusted for utilization. The *Oil and Gas Journal* reports unit capacity in barrels per stream day, which represents the maximum throughput for a given unit (Thrash, 1991).

This capacity was reduced based on the total refinery calendar-day throughput and the reported refinery utilization for 1990 of 86.6% (Thrash, 1991; EIA, 1991).

Product Transportation

The approach used to estimate carbon dioxide emissions from product transportation is similar to that used for crude transportation. Emission factors were determined for the previous API study (Radian, 1991) for the various modes of transport (reported in tons CO_2/bbl-mile), and activity factors are reported in ton-miles of product transported for the same modes (Eno, 1991). The activity factor units were converted to barrel-miles based on an average product density of 6.99 lb/gal. This was determined from heat equivalent conversion factors ranging from 3.625 to 6.287 million BTU/barrel and from 40.19 to 47.49 Terajoules per 1000 metric tonnes (EPA, 1994; IPCC, 1995).

Section 4
METHODOLOGY FOR PROJECTIONS TO 2000

Section 3 presented the estimation of emissions for the year 1990. This section outlines methods for projecting emissions of methane and carbon dioxide from a base year of 1990 to the year 2000. The intent is to estimate how potential changes in the petroleum industry segments will affect emission factors and activity factors. Sections 4.1 and 4.2 discuss methods for projecting activity factors for methane and carbon dioxide, respectively. Section 4.3 presents potential changes to emission factors resulting from proposed regulations and from energy efficiency improvements.

METHODOLOGY FOR METHANE ACTIVITY FACTOR PROJECTIONS

Many of the activity factors are volumes or mass of oil produced and processed. The methods selected for projecting those activity factors to the year 2000 are discussed in the following section. The activity factors for the volume of crude produced, transported, and refined will be evaluated using a mass balance of the petroleum industry.

Production

The activity factor for methane is based on the total production of oil. Since two valid forecast methods were available for projecting oil production to the year 2000, this report has averaged the two methods. Each forecast method is described below:

Forecast Method 1: Domestic crude production (including condensate) for the year 2000 is projected to be 5.35 MM bbl/d (EIA, 1995).

Forecast Method 2: Crude oil production for the year 2000 is projected to be 6.35 MM bbl/d (DRI, 1993) For comparison, this source reported 1990 production as 7.37 MM bbl/d compared to 7.355 MM bbl/d from EIA's *Petroleum Supply Annual* (EIA, 1991). This indicates that the source is starting at essentially the same place as the 1990 emission estimate discussed in Section 3.

The net result is an average activity factor of 5.85 MM bbl/d ± 0.5 MM bbl/d for the year 2000.

Crude Transportation

The most recent version of *Transportation in America* estimates millions of tons of crude and products transported domestically by various transport modes for 1993, and reports values for 1980 through 1992 (Eno, 1994). Regressing these data linearly and then extrapolating to the year 2000 results in the projected volume of crude transported. Figures showing the extrapolation results are provided in Appendix A. The breakdown of crude transportation projections by mode are shown in Table 4-1.

Table 4-1. Crude Handling Activity Factor Comparison for CH_4.

Transport Mode	10^6 Tons Crude, 1990	10^6 Tons Crude, 2000
Marine	299.3	232.6
Truck	24.6	16.3
Rail	1.12	1.95
Pipeline	611.6	601.2

To complete a petroleum mass balance (presented later in this section), the volume of crude handled due to imports and exports is extrapolated based on 1990-1994 import data from the *Petroleum Supply Annual* (EIA, 1995). For 1990, these volumes were 2,151 MM bbl imported and 39.8 MM bbl exported. The extrapolated volumes for 2000 are 3,120 MM bbl imported and 7 MM bbl exported (Appendix A).

Crude handling emissions result primarily from the loading of petroleum crude, since vapors in the transportation carriers are displaced to the atmosphere when the crude oil is loaded. Therefore, the unloading of imported crude does not contribute to the emission estimate. Incidently, IPCC's general guidelines for dealing with international transport is to not include these emission factors in the national totals, but to report them separately (IPCC, 1995).

Refining

The refining activity factor for methane is based on actual refinery throughput, which is calculated from total refinery capacity and adjusted based on utilization (bbl/d). Capacity for the year 2000 is estimated to be 15.915 MM bbl/d = 5,809 MM bbl/yr with utilization projected to be 88.5% (DRI, 1993). This source reports 1990 data as 5,683 MM bbl/yr capacity and 86.1% utilization, which compares well with 5,650 MM bbl/calendar year capacity and 86.6% utilization used in Section 3 (Thrash, 1991; EIA, 1991).

Product Transportation

This industry segment does not contribute to CH_4 emissions, so an estimated change in the activity factor is not necessary.

Mass Balance

The activity factors for the volume of crude produced, transported, and refined are quality checked in this section using a mass balance of the petroleum industry. Volumes of crude are converted to mass based on a crude density of 7.51 lb/gal; volumes of refined product are converted to mass based on a density of 6.99 lb/gal. The mass balance of the activity factors used for year 1990 and year 2000 activity factors are shown in Table 4-2 in units of million tons per year. Considering the data were from several sources, the mass of oil in each segment compares well, particularly for production and refining.

Table 4-2. Petroleum Mass Balance, MM Tons/yr.

Industry Segment		1990	2000
Production	Produced	423.4	336.7
	Imports	399.3	492.7
	Exports	-6.3	-1.1
	TOTAL	756.4	827.7
Crude Transport	Marine	606.1	601.2
	Truck	293.7	232.6
	Rail	24.4	16.3
	Pipeline	1.6	2.0
	TOTAL	925.8	852.1
Refining	Inputs	771.9	810.8
Product Transport	Marine	451.3	533.2
	Truck	159.1	170.0
	Rail	458.0	430.0
	Pipeline	29.5	36.3
	TOTAL	1097.9	1169.5

The crude and refined product transportation segments do show more oil being transported than produced or refined. However, the source of these data admits duplication for tons of oil transported by different modes (Eno, 1994). Emission calculations for these segments are based upon ton-miles of crude or product transported (tons of crude are used for CH_4 emissions from crude transport) and need to include emissions that result from multiple modes of transport for the same volume of oil. In other words, if one barrel of crude was transported by marine, then rail, then truck, and then pipeline, it should show up multiple times in the ton-mile analysis. So the fact that the total volume of oil transported is higher than that refined is realistic and does not lead to an overestimate of emissions.

METHODOLOGY FOR CO_2 ACTIVITY FACTOR PROJECTIONS

Production

For carbon dioxide emissions in the production segment, three activity factors were used to determine the 1990 emissions in Section 3: number of wells drilled, total number of active wells, and volume of gas flared. Methods for extrapolating each of these activity factors are listed below.

- The number of wells drilled in the year 2000 are projected to be 30,800 (DRI, 1993).
- The number of active wells for the year 2000 (548,497) is determined from linear extrapolation (Appendix A) based on 1989 through 1994 active well count data from the *Annual Energy Review* (EIA, 1995b)
- The volume of gas flared (146,038 million scf) is based on linear extrapolation (Appendix A) of reported vented and flared gas volumes for the years 1975 through 1992 (EIA, 1995b). The same ratio of gas flared versus vented as was used in Section 3 is used to estimate emissions for the year 2000 (EPA, 1994).

Crude Transportation

The most recent version of *Transportation in America* estimates ton-miles of crude by various transport modes for 1993, and reports values for 1980 through 1992 (Eno, 1994). Regressing these data and then extrapolating to the year 2000 results in the updated activity factor shown in Table 4-3. Figures showing the extrapolation results are provided in Appendix A.

Table 4-3. Crude Handling Activity Factor Comparison for CO_2.

Transport Mode	Ton-miles Crude, 1990	Ton-miles Crude, 2000
Marine	300.3	183.4
Truck	1.5	1.2
Rail	0.5	0.8
Pipeline	334.5	307.6

The volume of crude imported and exported was discussed previously.

Note, the energy attributed to the domestic crude production rate is 11.33 e-15 BTU/yr (EIA, 1994). This value is required for converting between volume and energy units for CO_2 emission estimates.

Refining

The refining activity factors for CO_2 emissions are based on capacity (bbl/d) for the individual refinery units. As stated previously, total capacity for the year 2000 is estimated to be 15.915 MM bbl/d. Individual unit capacities were used in Section 3 to determine 1990 emissions, and are projected here to the year 2000 using the following assumptions: 1) a constant feed distribution through the various refinery units, and 2) the same percentage increase in total refinery capacity applies to each unit. That is, where total refinery capacity is projected to increase from 5,650 MM bbl/year to 5,809 MM bbl/yr, an increase of 2.8%, the same increase is applied to each refinery unit.

Product Transportation

The most recent version of *Transportation in America* estimates ton-miles of petroleum products by various transport modes for 1993, and reports values for 1980 through 1992 (Eno, 1994). Regressing these data and then extrapolating to the year 2000 results in the updated activity factors shown in Table 4-4. The extrapolation results are provided in Appendix A.

Table 4-4. Product Transport Activity Factor Comparison for CO_2.

Transport Mode	Ton-miles of Petroleum Products, 1990	Ton-miles of Petroleum Products, 2000
Marine	154.2	134.1
Truck	28.2	31.6
Rail	13.3	14.9
Pipeline	249.3	272.8

METHODOLOGY FOR EMISSION FACTOR PROJECTIONS

Numerous factors will affect U.S. programs and policies for reducing methane and carbon dioxide emissions. It is unlikely that long-term programs and policies for greenhouse gas emission reductions will disappear within the next 10 years, but the form they will take is uncertain. This section summarizes the impact of proposed regulations and of energy efficiency changes on methane and carbon dioxide emissions from the U.S. petroleum industry. The proposed regulations considered were the Maximum Achievable Control Technology (MACT) standards promulgated under the Clean Air Act Amendments.

It should be noted that CO_2 is not regulated under the Clean Air Act, and therefore there are no requirements to develop National Ambient Air Quality Standards or air emission performance standards that directly regulate CO_2 emissions. In response to an international climate change treaty, EPA released the Climate Change Action Plan (CCAP) in October 1993, which included a number of initiatives for reducing CO_2 emissions in the United States. The CCAP states that investing in energy efficiency is the single most cost-effective method of reducing CO_2 emissions.

MACT summaries are organized by segment in the following subsections, which list the available data and the suggested approach and results. The effect of MACT varies widely, depending on the expected compliance dates, the expected percentage of equipment that will be covered by the MACT, and the specific requirements of the MACT. Most of the MACT analysis came from interpretation of the Background Information Document (BID) associated with each regulation.

Energy efficiency impacts on emission factors are presented following the MACT discussion.

Oil and Gas (O&G) Production MACT

The following general data were used to evaluate the MACT impact on emission factors for oil production:

Source of Regulation:	NESHAP Subpart HH (40 CFR 63.764)
Effective Date of Regulation:	Rule is scheduled for promulgation in 1997
Compliance Period:	3 years
Reference Material:	• Preliminary Draft BID for Proposed Oil and Gas Production MACT (no EPA report number as of June 1994) • Preliminary Draft MACT for Oil and Gas Production (January 1995)

CH_4 Emissions — The effect of the Oil and Gas MACT on CH_4 emissions could not be easily determined because the language of the MACT does not specifically address these emissions. However, some general data can be extracted and used with reasonable assumptions to predict the MACT impact. For CH_4, a 70% reduction will be applied to the emission factor. The following paragraphs explain the basis for the reduction.

Methane emissions from equipment leaks and storage vessels are difficult to subdivide between gas industry and petroleum industry since the Background Information Document (BID) only reported baseline methane emissions from combined oil and gas operations. For the purpose of this study, the assumption was made that the impact of the MACT is equivalent for the oil versus gas industry.

The preliminary draft MACT proposes that equipment leaks at major sources must be controlled by a leak detection and repair (LDAR) program. This includes gas processing plants and offshore platforms. There is a discrepancy between the draft MACT and the BID because the BID presents post-MACT equipment leaks at major sources based on a 70% reduction for control of gas processing plants and offshore platforms, but also included tank batteries. Tank batteries were not subject to LDAR in the draft MACT. This study will make an assumption that this reduction does not include tanks, which will be treated separately. This study will also assume that there is a 50/50 split between the emissions related to fugitives versus emissions related to venting, flaring and maintenance.

The BID storage tank emission estimates reference an old (1978) EPA report. It is unclear whether appropriate corrections and adjustments were made (such as using the latest AP-42 tank calculations). The BID projects a 93% reduction in methane emissions from storage vessels and containers that would be controlled by MACT at major sources. This was a combination of venting storage tanks to a 95% effective control device plus submerged fill (instead of splash filling) containers. For tanks, this study assumes that a 93% reduction will be applied to 10% of the existing emissions, based on the assumption that only 10% of the production sites will implement the MACT by 2000. The new EF for tanks is therefore 10.97 scf CH_4/bbl production.

The BID estimated CH_4 emissions from tank batteries to be 110,000 Mg/yr (which includes equipment leaks, storage tanks, and containers), and methane from produced water to be 330,000 Mg/yr. The contribution from produced water is quite different (higher) compared to estimates of methane emissions from brine/water tanks in other references. This study ignores that discrepancy.

An overall concern is that in the MACT baseline emissions were segregated by major and area sources (some MACT standards only apply to major sources). The emission estimates after MACT is applied could depend on both these percentages. This study assumes that 10% of the oil production facilities implement the MACT recommendations by the year 2000. This is based upon two assumptions: 1) the fact that not all facilities will qualify as major sources, and therefore only a fraction will have to comply, and 2) the Oil and Gas (O&G) MACT may not even require compliance by the year 2000. In fact, the O&G MACT has not even reached proposal stage, and if the

MACT were proposed in 1996, there is a 3 year period before compliance is required. Therefore, given the uncertainty of any implementation of the Oil and Gas MACT before 2000, 10% appears to be a reasonable estimate. Therefore, the emission factor of 7,664 kg CH_4/PJ for 1990 will be reduced to 7,396 kg/PJ for the year 2000.

Methane emissions from process vents in the MACT are only attributed to glycol dehydrators, which are considered part of the gas industry based on the boundary definitions discussed in Section 1.

CO_2 Emissions — Carbon dioxide emissions are due to the percentage of storage tanks and process vents which will use incineration or flaring for control. The BID estimates 10% of the affected sources will use combustion control. Table 5-6 in the BID shows secondary impacts of MACT but is limited to NOx, SOx, and CO. The emission factors used could not be easily checked in a way that would allow CO_2 emissions to be estimated.

CO_2 projections were made by using the assumptions applied for methane: 10% of the production facilities implement the MACT. An additional assumption is that 10% of the affected sources use combustion control (as opposed to recovering emissions).

Marine Vessel Recovery (MVR) MACT

The following general data were used to evaluate the MACT impact on crude transportation emission factors:

Source of Regulation:	NESHAP Subpart Y (40 CFR 63.560)
Effective Date of Regulation:	August 1995
Compliance Period:	3 years (RACT) or 4 years (MACT)
Reference Material:	Technical Support Document for Development of VOC Rule for Marine Loading Operations (EPA report EPA-450/3-92-001a; May 1992)

CH_4 Emissions — Methane is assumed to be emitted only from crude oil loading (other commodities such as gasoline, toluene, jet fuel, etc. would not appear to contain CH_4). Per AP-42 Sec.4-4 (EPA, 1995), a methane composition of 15% of total organic carbon from crude is assumed. The baseline CH_4 emissions were estimated in the MACT as:

$$(1.1\ 10^8 \text{ lb/yr VOC})(0.15/0.85) = 1.9 \times 10^7 \text{ lb/yr } CH_4 \text{ (or 9,500 TPY } CH_4\text{)}$$

Considering the effect of the MVR MACT, Regulatory Alternative "E" is believed to most closely approximate the final rule (refer to Table 4-1 in the technical support document). This equates to a 70% reduction in VOC emissions. There are insufficient data in the technical support document (TSD) to estimate whether the rule would result in 70% of the crude loading becoming controlled. However, using that assumption, the remaining post-MACT CH_4 emissions would be:

$$(1.9 \times 10^7 \text{ lb/yr CH4})(30\% \text{ uncontrolled}) = 5.8 \times 10^6 \text{ lb/yr } CH_4 \text{ (or 2,900 TPY } CH_4\text{)}$$

Applying the same 70% reduction to the marine transport emission factor, reduces the EF value from 745 kg/PJ (Table 3-1) to 223.5 kg CH_4/PJ.

CO_2 Emissions — Carbon dioxide emissions due to the MVR MACT are estimated in the technical support document (TSD) which provides an increase of 179,500 tons per year of CO_2 resulting from the combustion of marine vessel loading vents.

For this study, CO_2 emissions for crude transport are attributed only to CO_2 emitted as a result of fuel combustion for the various transport modes. The MACT results in an additional emission source - marine vessel vents. The net CO_2 emissions from crude handling losses are increased by 179,500 tons CO_2 per year for the 2000 projections; the corresponding emission factor and activity factor for this new source were not estimated.

Refinery MACT

The following general data were used to evaluate the MACT impact on refinery emission factors:

Source of Regulation:	NESHAP Subpart CC (40 CFR 63.640)
Effective Date of Regulation:	July 1995
Compliance Period:	3 years plus additional time for tank retrofits
Reference Material:	• BID for Final Standards - NESHAP for Petroleum Refineries (EPA report EPA-453/R-95-015b; July 1995). • Regulatory Impact Analysis for Petroleum Refinery NESHAP (Revised Draft for Promulgation) - PETRORIA.WPF. • Preamble to Final Rule - PETROPRE.WPF.

CH_4 Emissions — The 1980 refinery study does not provide data for conversion of VOC emissions to CH_4. There is only a footnote in an old AP-42 section which states that less than 1 wt% of total VOC emissions are methane (EPA, 1995). Therefore, based on estimates in Table 2 of the preamble to the final rule, the baseline methane equipment leak emissions would be:

$$(189{,}000 \text{ Mg/yr VOC})(1 \text{ wt\% } CH_4) = 1{,}890 \text{ Mg/yr } CH_4 \text{ (or 2,080 TPY } CH_4\text{)}$$

After implementation of Refinery MACT, the remaining methane equipment leak emissions would be:

$$(189{,}000 - 146{,}000 \text{ Mg/yr VOC})(1 \text{ wt\% } CH_4) = 430 \text{ Mg/yr } CH_4 \text{ (or 470 TPY } CH_4\text{)}$$

which is a 77% reduction. This 77% reduction was applied to the 1990 CH_4 emission factor for refinery operations, reducing the emission factor from 355 kg CH_4/PJ (Table 3-1) to 82 kg CH_4/PJ.

Storage tank emissions were described in the regulatory impact analysis (RIA). This document lists 13 "major" petroleum liquids which account for over 80% of the baseline VOC emissions. The only liquid that would probably contribute to CH_4 emissions is crude oil. Per AP-42 Sec.4-4, assume methane is 15% of total organic carbon from crude (EPA, 1995). Data on the percent of refinery storage tank emissions normally contributed by crude storage could not be identified; professional judgement leads to an assumption of 25%. Therefore, the baseline CH_4 storage tank emissions would be:

$$(111{,}000 \text{ Mg/yr VOC})(25\% \text{ from crude})(0.15/0.85) =$$
$$4{,}900 \text{ Mg/yr } CH_4 \text{ (or } 5{,}400 \text{ TPY } CH_4)$$

After implementation of Refinery MACT, the remaining methane storage tank emissions would be:

$$(111{,}000 - 21{,}000 \text{ Mg/yr VOC})(25\%)(0.15/0.85) = 3{,}970 \text{ Mg/yr CH4 (or } 4{,}380 \text{ TPY } CH_4)$$

which is a <u>20% reduction</u> in methane emissions. Applying the 20% reduction to the 1990 CH_4 emission factor for refinery storage tanks reduces the emission factor from 4.37×10^7 ton CH_4/bbl (Table 3-1) to 3.5×10^7 ton CH_4/bbl.

According to the preamble of the final petroleum refinery rule, baseline VOC emissions from process vents would be <u>reduced by 78%</u> under Refinery MACT. Assuming the methane content of baseline process vents is 10 wt%[1], the baseline methane process vent emissions would be:

$$(109{,}000 \text{ Mg/yr VOC})(10\% \text{ CH4}) = 10{,}900 \text{ Mg/yr CH4 (or } 12{,}000 \text{ TPY } CH_4)$$

[1]The assumption of the percent of methane in the process vents (10%) is not likely to be validated from any existing data. We know of no publicly available measurements of refinery vents that include methane. This assumption appears to be reasonable given the large amount of cracking and light end units in refineries.

After implementation of Refinery MACT, the remaining methane process vent emissions would be:

$$(109{,}000 - 85{,}000 \text{ Mg/yr VOC})(10\% \; CH_4) = 2{,}400 \text{ Mg/yr } CH_4 \text{ (or } 2{,}640 \text{ TPY } CH_4\text{)}$$

Since Benzene Waste Operations NESHAP (BWON) was originally promulgated in March 1990 and refineries were scheduled to be in compliance by April 1993 (with additional time extensions available if a compliance waiver was requested), this project assumes that CH_4 emission reductions as a result of BWON are minor and should not be estimated.

CO_2 Emissions — Carbon dioxide emissions would not occur from equipment leaks. CO_2 emissions could occur for fixed roof tanks subject to control by routing vapors to a combustion device. However, the Refinery MACT Regulatory Impact Assessment (RIA) assumed that refineries have pre-existing fuel gas collection systems and/or flare systems. Therefore, the RIA did not estimate costs or CO_2 impacts since these systems already exist. In addition, the RIA based the control cost estimates on tank retrofits to an internal floating roof (with no CO_2 impact). No change was made to the CO_2 refinery emission factors based on the Refinery MACT. However, the emission factors were adjusted based on improved efficiencies, discussed later.

Gasoline Distribution MACT

The following general data were used to evaluate the MACT impact on product transport emission factors:

Source of Regulation:	NESHAP Subpart R (40 CFR 63.420)
Effective Date of Regulation:	December 1994
Compliance Period:	3 years
Reference Material:	BID for Gasoline Distribution Industry - Stage I (EPA report EPA-453/R-94-002b; November 1994)

CH4 Emissions — Methane is unlikely to be emitted from any of the regulated sources with or without this MACT standard.

CO_2 Emissions — Carbon dioxide emissions due to the Gasoline Distribution MACT can be estimated from data presented in the BID. Table D-1 (Summary of Nationwide Emission Reductions and Cost Impacts of the Final Rule) provides an estimate of 12,500 Mg/yr of VOC reduction resulting from the MACT standard. As stated on pages 1-13 and 13-3 in the BID, combustion controls would be used by 75% of the sources, with the remaining 25% using recovery controls (carbon absorbers or refrigerated condensers). The increased CO_2 emissions resulting from Gasoline Distribution MACT are estimated below:

(12,500 Mg/yr VOC reduction)(75% using combustion) = 9,375 Mg/yr VOC combusted

Assuming this is butane (MW= 58 g/gmol), the CO_2 emissions would be:

$$(9375 \times 10^6 \text{ g/yr butane})(\text{gmol}/58 \text{ g})(4 \text{ gmol } CO_2/\text{gmol butane})(44 \text{ g } CO_2/\text{gmol}) = 28{,}450 \text{ Mg/yr (or } 31{,}300 \text{ TPY } CO_2)$$

As with crude transport, CO_2 emissions from product transport are based on the CO_2 emitted due to fuel combustion associated with the various transport modes. Additional CO_2 emissions resulting from the use of combustion controls are included in the 2000 projections as a new emissions source of 31,300 ton CO_2/year. This amount is included in the net CO_2 emissions estimated for product transport. The emission factor and activity factor corresponding to this source are not estimated.

Energy Efficiency Changes

Energy efficiency improvements can reduce the amount of fuel used per activity, and therefore reduce the net emission factor over time. Based upon industry reviewer comments, this study has limited projected changes to energy efficiency improvements in refineries. Improvements in other segments are not expected to be as significant.

Between the years 1990 and 2000, refinery energy efficiency is expected to improve. Increasing electricity costs and environmental costs associated with fuel use in heaters will drive refiners to improve energy efficiency as a way of controlling operating costs (Hall, 1991). Systems such as power recovery turbines, co-generation, more efficient heat exchanger, highly efficient burners, and control systems that maximize thermal efficiencies will be increasingly used.

Only a few national forecasts specify energy efficiency improvements between 1990 and 2000. None are specific to the refining sector. The Department of Energy's Annual Energy Outlook does forecast overall U.S. industry energy intensity changes (EIA, 1995c). Energy intensities are calculated as energy use per dollar of gross domestic production (GDP). Energy intensities are surrogates for energy efficiencies since dollar GDP estimates are surrogates for actual output. As such, a huge price change or significant market fluctuation could make energy intensity indicators appear higher or lower than the actual change in intensity and higher or lower than the actual change in efficiency (EIA, 1995d).

Nevertheless, since there is a dearth of energy efficiency data, this report has assumed that energy intensity forecasts are equivalent to energy efficiency forecasts. For 1993 through 2010, EIA predicts a decrease in energy intensity (energy use per dollar of GDP) of 1.2 percent per year (EIA, 1995c). However, this figure is for all sectors of the U.S. economy. For the industrial sector, EIA predicts a 0.9% average annual drop in energy intensity between 1993 and 2010. High industrial growth cases analyzed by EIA show significantly better improvements in energy intensity. However, these generic U.S. industry cases assume that new output results from incremental, new, more efficient facilities. This is not the case for U.S. refineries as no new U.S. refineries will be built in the foreseeable future (Hall, 1991); economic and environmental considerations ensure that no new grassroots facilities will be built. However, there will be considerable investment in refinery upgrading and modernization which will likely improve efficiency.

It is reasonable to expect that there is a learning curve affecting refinery efficiency improvements. In other words, the improvements are not linear over time; diminishing returns should be expected. In fact, some actual Canadian data supports this expectation. Canadian refinery data are also available from a study of participants in the Canadian Energy Program for Energy Conservation on the Canadian petroleum refining sector (Nyboer, 1995). Again, the data is based upon an energy intensity index, the Solomon Energy Intensity Index. For 1972 through 1990, the total energy efficiency improvements amounted to 32.5%. When compounding is removed, this equates to approximately 2.0 % per year efficiency improvement for 1972 through 1990. The study also shows that actual improvements for 1990 through 1994 totaled to only 2.0 %, or approximately 0.5 % per year energy efficiency per throughput. Canadian refineries are believed by the Canadians to be very similar to U.S. refineries.

Therefore this API report uses a conservative estimate of ***0.5%*** per year energy use reduction (energy efficiency improvement) from 1990 through 2000. While this is lower than the EIA general industry forecast, it is supported by Canadian data specific to refineries. In reality, this forecast is very uncertain, since there may be offsetting changes that increase energy consumption. For example, there is a declining quality of world crude oil production over the forecast period (EIA, 1995c). The production of light, low-sulfur crude is expected to peak and decline around the turn of the century. Heavier, higher sulfur crude can result in higher energy costs per barrel of product. Also, with more stringent specifications resulting from environmental regulations, refining becomes more complex, more energy intensive, and more expensive.

This report has used the 0.5% per year reduction in energy use to alter the total refining CO_2 emission projection. For the year 2000, this is a net 5.1% reduction in the 1990

CO_2 emission factor. Methane emissions remain unaffected, since they result mostly from fugitive emissions which are not affected by energy efficiency. The reduction was applied to all refinery CO_2 emissions, since all of these emissions were assumed to result from fuel consumption.

Section 5

EMISSIONS AT YEAR 2000

Section 4 presented the methods used to modify emission factors and activity factors from those used for the year 1990 to produce reasonable estimates for the year 2000. Section 4 used anticipated changes in the petroleum industry segments to modify activity factors, and used potential changes from proposed regulations and from expected energy efficiency improvements to modify emission factors. This section uses those projected activity and emission factors to calculate emissions of methane and carbon dioxide for the year 2000.

Tables 5-1 and 5-2 present the summary tables for methane and carbon dioxide similar to Tables 3-1 and 3-2 presented for the year 1990 in Section 3. Tables 5-3 and 5-4 provide a background summary of the basis for the methane activity factors and emission factors, respectively. Tables 5-5 and 5-6 provide a background summarizing the basis for the carbon dioxide activity factors and emission factors, respectively.

Table 5-1. Methane Emission Projections for 2000.

API Emission Estimate for CH4 2000 Projections	CH4 EF	EF units	CH4 AF	AF units	CH4 tons	Subtotals CH4 tons
1. Production						600,346
Fugitives, Maint., V&F	7396	kg/PJ prod.	5,850,000	bbl/d	106,436	
Tanks	10.97	scf/bbl	5,850,000	bbl/d	493,910	
2. Crude Handling Losses						4,041
Marine Transport	223.5	kg/PJ oil trans.	232.6	10^6 tons	2,857	
Truck Transport	1.02E-05	t/bbl	16.3	10^6 tons	1,057	
Rail Transport	1.02E-05	t/bbl	1.95	10^6 tons	127	
Pipeline	0	t/bbl	601.2	10^6 tons	0	
3. Refining						4,641
Refinery Operations	82	kg/PJ refined	14,084,800	bbl/d	2,841	
Tanks	3.5E-07	t/Bbl throughput	14,084,800	bbl/d	1,799	
4. Product Transport	0	t/bbl	N/A	10^6 tons	0	0
Total, tons CH4						609,027
Total, Bscf CH4						29

Table 5-2. Carbon Dioxide Emission Projections for 2000.

API Emission Estimate for CO2 2000 Projections	CO2 EF	EF units	CO2 AF	AF units	CO2 Emissions 10^6 tons/yr	Subtotals CO2 MMton/y
1. Exploration/Extraction						96.77
Drilling	2887.4	ton CO2/well	30,800	wells drilled	88.93	
Extraction	1.2	ton CO2/well	548,497	active wells	0.66	
Flared	537	g C/m^3	3.3083E+09	m^3	7.18	
2. Crude Handling Losses						7.60
Truck Transport	1.1E-05	ton CO2/Bbl mile	7.600E+09	Bbl mile	0.09	
Marine Transport	1.3E-06	ton CO2/Bbl mile	1.162E+12	Bbl mile	1.45	
Rail Transport	6E-06	ton CO2/Bbl mile	5.070E+09	Bbl mile	0.03	
Pipeline	3E-06	ton CO2/Bbl mile	1.949E+12	Bbl mile	5.85	
Marine Vessel Loading					0.18	
3. Refining						174.49
Flaring	3.5E-05	ton CO2/Bbl	5.254E+09	Bbl	0.18	
-Atm Sep	0.007923	ton CO2/Bbl	5.254E+09	Bbl	41.62	
-Thermal processes	0.078433	ton CO2/Bbl	6.499E+08	Bbl	50.97	
-Cat reforming	0.001584	ton CO2/Bbl	1.257E+09	Bbl	1.99	
-Cat hydrorefining	0.023768	ton CO2/Bbl	7.885E+08	Bbl	18.74	
-Alkylation/Polymerization	0.028521	ton CO2/Bbl	3.757E+08	Bbl	10.72	
-Hydrogen	0.017694	ton CO2/MMcf	7.984E+05	MMcfd	0.01	
-Vacuum Sep/Dist	0.007923	ton CO2/Bbl	2.277E+09	Bbl	18.04	
-Cat cracking	0.007923	ton CO2/Bbl	1.839E+09	Bbl	14.57	
-Cat hydrocraking	0.015845	ton CO2/Bbl	4.063E+08	Bbl	6.44	
-Cat hydrotreating	0.000594	ton CO2/Bbl	2.343E+09	Bbl	1.39	
-Arom/Isom	0.026936	ton CO2/Bbl	2.695E+08	Bbl	7.26	
-Lubes	0.012877	ton CO2/Bbl	7.240E+07	Bbl	0.93	
-Asphalt	0.006021	ton CO2/Bbl	2.413E+08	Bbl	1.45	
-Cokes	0.006312	ton CO2/ton	2.496E+07	t/d	0.16	
Tanks	0	ton CO2/Bbl	5.254E+09	Bbl	0.00	
4. Product Transport						9.44
Truck Transport	1E-05	ton CO2/Bbl mile	2.153E+11	Bbl mile	2.20	
Marine Transport	1.1E-06	ton CO2/Bbl mile	9.135E+11	Bbl mile	1.00	
Rail Transport	5.3E-06	ton CO2/Bbl mile	1.015E+11	Bbl mile	0.54	
Pipeline	3.1E-06	ton CO2/Bbl mile	1.858E+12	Bbl mile	5.67	
Gasoline Distribution MACT					0.03	
Total, MMtons CO2						288
Total, Bscf CO2						4,972

Table 5-3. Methane Emission Projections - Activity Factor Sources.

API Emission Estimate for CH4 2000 Projections	Activity Factor Sources
1. Production	
Fugitives, Maint., V&F	Average of projections from (EIA, 1995b) and (DRI/McGraw Hill, 1993)
Tanks	Average of projections from (EIA, 1995b) and (DRI/McGraw Hill, 1993)
2. Crude Handling Losses	
Marine Transport	Linear Extrapolation from Transportation in American reported values (multiple years)
Truck Transport	Linear Extrapolation from Transportation in American reported values (multiple years)
Rail Transport	Linear Extrapolation from Transportation in American reported values (multiple years)
Pipeline	Linear Extrapolation from Transportation in American reported values (multiple years)
3. Refining	
Refinery Operations	Based on 15.915 MMbbl/d and 88.5 capacity from (DRI/McGraw Hill, 1993)
Tanks	Based on 15.915 MMbbl/d and 88.5 capacity from (DRI/McGraw Hill, 1993)
4. Product Transport	Not considered a source of emissions, so no estimate was developed for 2000.

Table 5-4. Methane Emission Projections - Emission Factor Sources.

API Emission Estimate for CH4 2000 Projections	Emission Factor Sources
1. Production	
Fugitives, Maint., V&F	Reduction based on MACT for fugitive sources.
Tanks	Reduction based on BID for storage tanks.
2. Crude Handling Losses	
Marine Transport	70% reduction based on Marine Vessel Loading MACT.
Truck Transport	(EPA, 1995) AP-42
Rail Transport	(EPA, 1995) AP-42
Pipeline	
3. Refining	
Refinery Operations	77% reduction based on MACT and assuming 1% CH4 in VOC.
Tanks	20% reduction estimated for crude storage tanks, assuming 15% CH4 in VOCs.
4. Product Transport	AP-42: Not considered a source for methane emissions. (EPA, 1995)

Table 5-5. Carbon Dioxide Emission Projections - Activity Factor Sources.

API Emission Estimate for CO2 2000 Projections	Activity Factor Sources
1. Exploration/Extraction	
Drilling	Year 2000 projection from (DRI/McGraw Hill, 1993)
Extraction	Extrapolated from Oil and Gas Journal (Beck, 1995)
Flared	Extrapolated from EIA Petroleum Supply Annual (EIA, 1995a) reported vented and flared volumes (multiple year
2. Crude Handling Losses	
Truck Transport	Linear extrapolation from Transportation in America, no change in density from 1990.
Marine Transport	Linear extrapolation from Transportation in America, no change in density from 1990.
Rail Transport	Linear extrapolation from Transportation in America, no change in density from 1990.
Pipeline	Linear extrapolation from Transportation in America, no change in density from 1990.
Marine Vessel Loading	Marine Vessel Loading MACT - no AF provided, only total ER.
3. Refining	
Flaring	Extraplotated from Oil & Gas Journal (Thrash, 1991) Annual Refining Survey
-Atm Sep	Based on calendar-day capacity and
-Thermal processes	Adjusted for 88.5% utilization from (DRI/McGraw Hill, 1993)
-Cat reforming	"
-Cat hydrorefining	"
-Alkylation/Polymerization	"
-Hydrogen	"
-Vacuum Sep/Dist	"
-Cat cracking	"
-Cat hydrocraking	"
-Cat hydrotreating	"
-Arom/Isom	"
-Lubes	"
-Asphalt	"
-Cokes	"
Tanks	"
4. Product Transport	
Truck Transport	Linear extrapolation from Transportation in America, no change in density from 1990.
Marine Transport	Linear extrapolation from Transportation in America, no change in density from 1990.
Rail Transport	Linear extrapolation from Transportation in America, no change in density from 1990.
Pipeline	Linear extrapolation from Transportation in America, no change in density from 1990.
Gasoline Distribution MACT	Gasoline Distribution MACT - no AF provided, only total ER.

Table 5-6. Carbon Dioxide Emission Projections - Emission Factor Sources.

API Emission Estimate for CO2 2000 Projections	Emission Factor Sources
1. Exploration/Extraction	
Drilling	(Radian, 1991) Combustion equipment (power gen. & other engines)
Extraction	(Radian, 1991) Combustion equipment (power gen. & other engines)
Flared	Increase in emissions due to use of combustion control for storage tanks and process vents.
2. Crude Handling Losses	
Truck Transport	(Radian, 1991) Fuel type and efficiency
Marine Transport	(Radian, 1991) Fuel type and efficiency
Rail Transport	(Radian, 1991) Fuel type and efficiency
Pipeline	(Radian, 1991) Fuel type and efficiency
Marine Vessel Loading	Marine Vessel Loading MACT - no EF provided, only total ER.
3. Refining	
Flaring	5.1% reduction based on improved refinery efficiency.
-Atm Sep	"
-Thermal processes	"
-Cat reforming	"
-Cat hydrorefining	"
-Alkylation/Polymerization	"
-Hydrogen	"
-Vacuum Sep/Dist	"
-Cat cracking	"
-Cat hydrocraking	"
-Cat hydrotreating	"
-Arom/Isom	"
-Lubes	"
-Asphalt	"
-Cokes	"
Tanks	(Radian, 1991) Not considered a source for CO2
4. Product Transport	
Truck Transport	(Radian, 1991) Average specific gravity of 6 products, fuel type and efficiency
Marine Transport	(Radian, 1991) Average specific gravity of 6 products, fuel type and efficiency
Rail Transport	(Radian, 1991) Average specific gravity of 6 products, fuel type and efficiency
Pipeline	(Radian, 1991) Average specific gravity of 6 products, fuel type and efficiency
Gasoline Distribution MACT	Gasoline Distribution MACT - no EF provided, only total ER.

Section 6
CONCLUSIONS

The approach used to estimate the United States petroleum industry CO_2 and CH_4 inventory for 1990 and for 2000 represents the best available approach for the level of emissions and activity data that is publicly available. The level of detail is comparable to the limited level of detail offered by IPCC for use in calculating country emissions of greenhouse gases. In fact, this API approach is preferable to the IPCC methodology in that it is specific to the petroleum industry (IPCC included all industries), and it includes sources that were omitted in the IPCC approach.

However, since most of the emissions for this report are calculated on an entire industry segment level, and none are calculated on an equipment detail level, this report's estimate will be inferior to an estimate from measurements performed on an equipment detail level. No such estimates exist today, though independent research efforts are underway that may produce more accurate results in the future (Radian, 1996c).

RESULTS

The total 1990 emissions of CO_2 from production through product transport are 284 MM tons, slightly less than the previous API report which showed 300 MM tons (Radian, 1991). The differences can be attributed to updated activity factors for the production and transportation industry segments, and accounting for refinery utilization in determining the 1990 refinery activity factors. The total methane emissions for 1990 are 0.848 MM tons, approximately two times the previous emission estimate of 0.392 MM tons (Radian 1992). The differences can be attributed to inclusion of production tank emissions and updated activity factors for this report.

Figures 6-1 and 6-2 illustrate how emissions from the petroleum industry compare to other U.S. anthropogenic sources of CO_2 and methane emissions, respectively (EPA, 1993; EPA, 1994; Radian, 1996). For CO_2 emissions, the petroleum industry accounts for approximately 5% of the total U.S. CO_2 emissions. Mobile sources (emissions resulting from petroleum fuels used in transportation) are the largest category of CO_2 emissions, followed by coal and natural gas. For methane emissions, the petroleum industry accounts for approximately 2.5% of total U.S. methane emissions, compared to the natural gas industry which accounts for 19%.[2] Landfills and agricultural sources account for the majority of anthropogenic methane emissions.

Emissions of methane projected for the year 2000 show a reduction of approximately 240,000 tons. The largest portion of this reduction occurs in the production segment from both reductions in the estimated emission factors and the projected crude production. Carbon dioxide emissions are projected to increase slightly from 284 million tons in 1990 to 288 million tons in the year 2000. Emissions of CO_2 decrease in the crude transport segment, but increase slightly in the other industry segments.

SENSITIVITY ANALYSIS

General sensitivity examinations were conducted to evaluate key sources of emissions. For CO_2, the largest emission sources are: drilling, refinery thermal processes, refinery atmospheric separation, and catalytic hydrorefining. The emission factors from these sources are known with a reasonable level of certainty. In addition, the activity factors for these categories are expected to be fairly constant for years examined in this study. Therefore, the CO_2 estimates in this study appear not to be very sensitive to the assumptions made.

[2] Data for the natural gas industry are based on results from the GRI/EPA Methane Emissions Project (Radian, 1996b). The base year for this study was 1993.

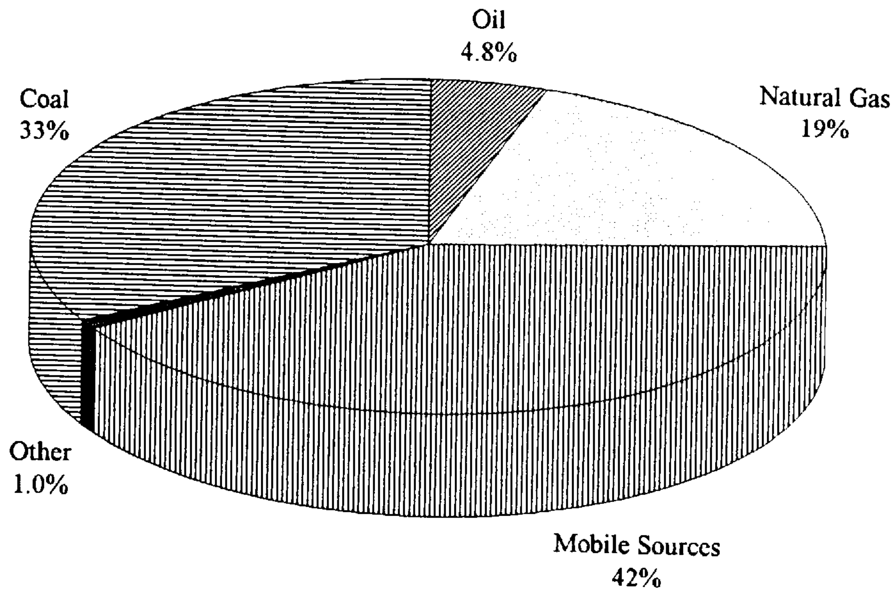

Figure 6-1. 1990 CO_2 Emissions.

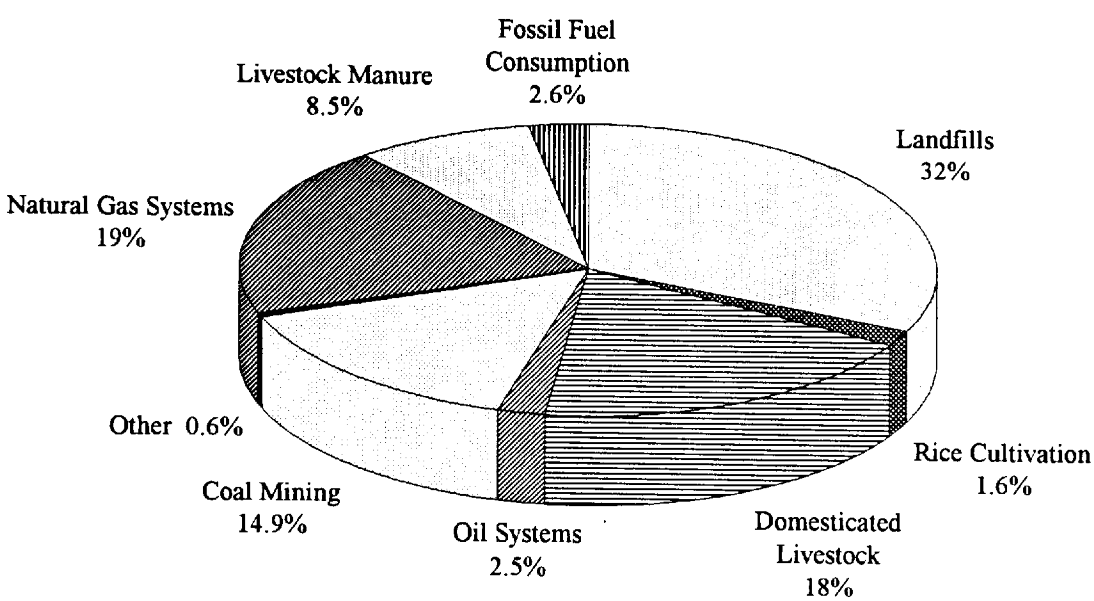

Figure 6-2. 1990 Methane Emissions.

The general sensitivity examination for methane revealed that the largest emission sources are production tanks and "fugitives, maintenance, and venting & flaring" emissions from production. These two sources, in which there is considerable uncertainty in the emission factors, dwarf the emission estimates for the other industry segments. Emission projections for these sources are based on production rate, which is somewhat uncertain for the year 2000. However, the emission factors for these categories are expected to remain fairly constant, or decline slightly over the period due to industry emission reduction measures. As a result, the trend in methane emissions will be flat to declining from 1990 to 2000. Although, the level of uncertainty in the methane emissions for 1990 and 2000 is greater than the carbon dioxide estimates, the trend in methane emissions is downward from the 1990 levels.

The emission estimates were also evaluated on a global warming equivalent basis. Using the Global Warming Potential (GWP) recommended by IPCC for a 100 year time period, methane emissions can be converted to an equivalent CO_2 basis, where a ton of methane has 24.5 times the global warming impact of a ton of carbon dioxide (IPCC, 1995). Table 6-1 shows the methane and CO_2 emission estimates and adjusted GWP emissions for the years 1990 and 2000.

Table 6-1. Estimated and Projected Emissions from the Petroleum Industry (Million Tons per Year).

	GWP	1990 Emissions	1990 Emissions GWP-Adjusted	2000 Emissions	2000 Emissions GWP-Adjusted	% Change
Carbon dioxide	1	284	284	288	288	1.4%
Methane	24.5	0.484	20.8	0.609	14.9	-28%
Total			305		303	-0.6%

Despite the larger impact of methane, the CO_2 emissions dominate the GWP-adjusted emissions from the petroleum industry. Therefore, the total estimates of emissions from the petroleum industry are likely not to be very sensitive to the assumptions made, despite the greater uncertainty in the methane emissions.

RECOMMENDATIONS

Through the process of creating updated emission estimates for this study, several recommendations for potential future work have been outlined:

1) Update the basis to an equipment detail level, especially for known large emission sources. For example, API could use data from related and ongoing API projects, such as the production tank VOC field measurement campaign. API could also use the results of the U.S. EPA study, *Methane Emissions from the Petroleum Industry*, when it is completed (Radian, 1996c).

2) Resolve boundary issues on broad segment level estimates, such as the IPCC venting and flaring estimate that does not separate gas industry emissions from petroleum industry emissions.

3) Complete a more detailed survey of U.S. oil field production practices. This would allow estimates for production field venting (such as casinghead venting, etc.), which have not been accurately quantified in any previous studies.

Section 7

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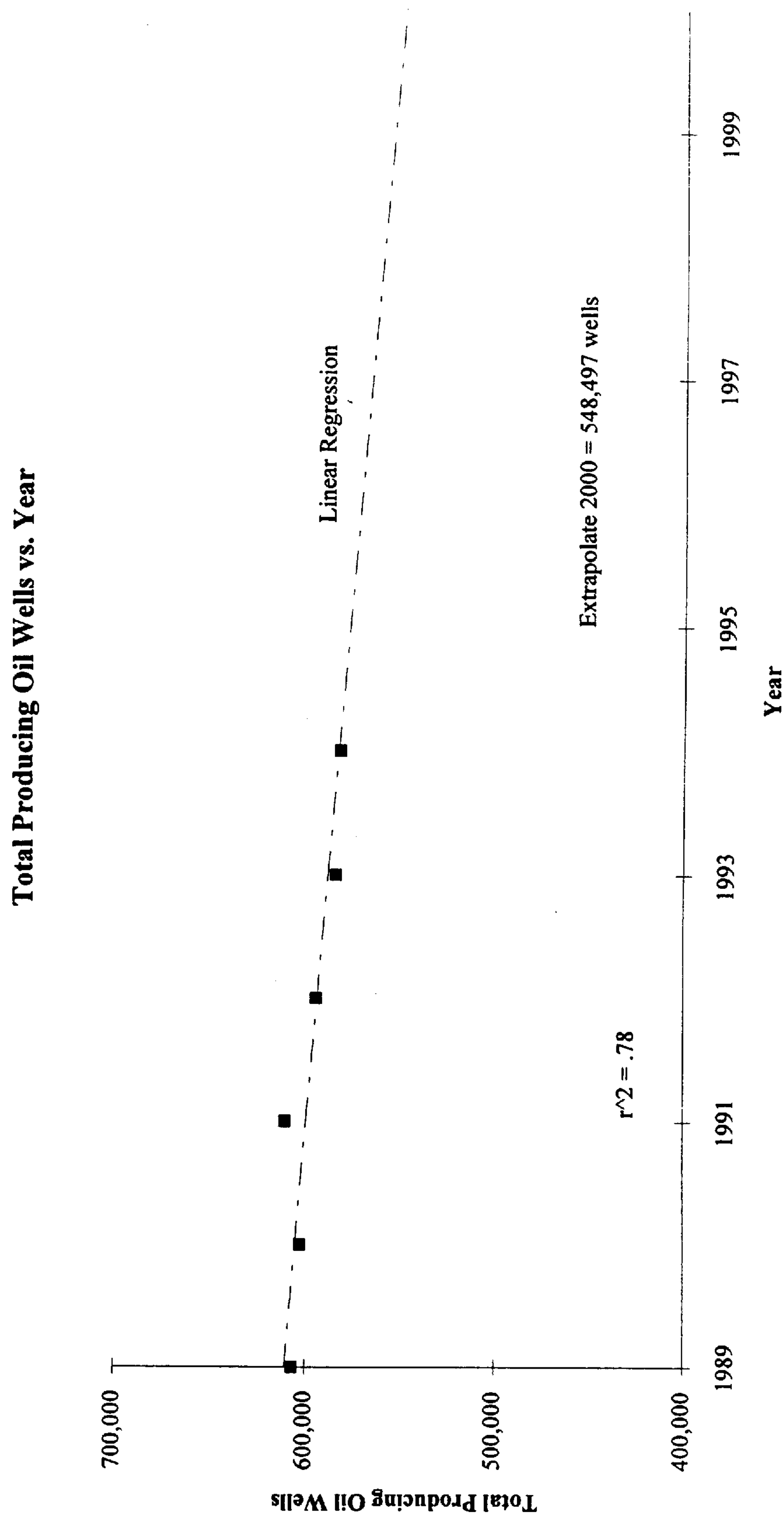
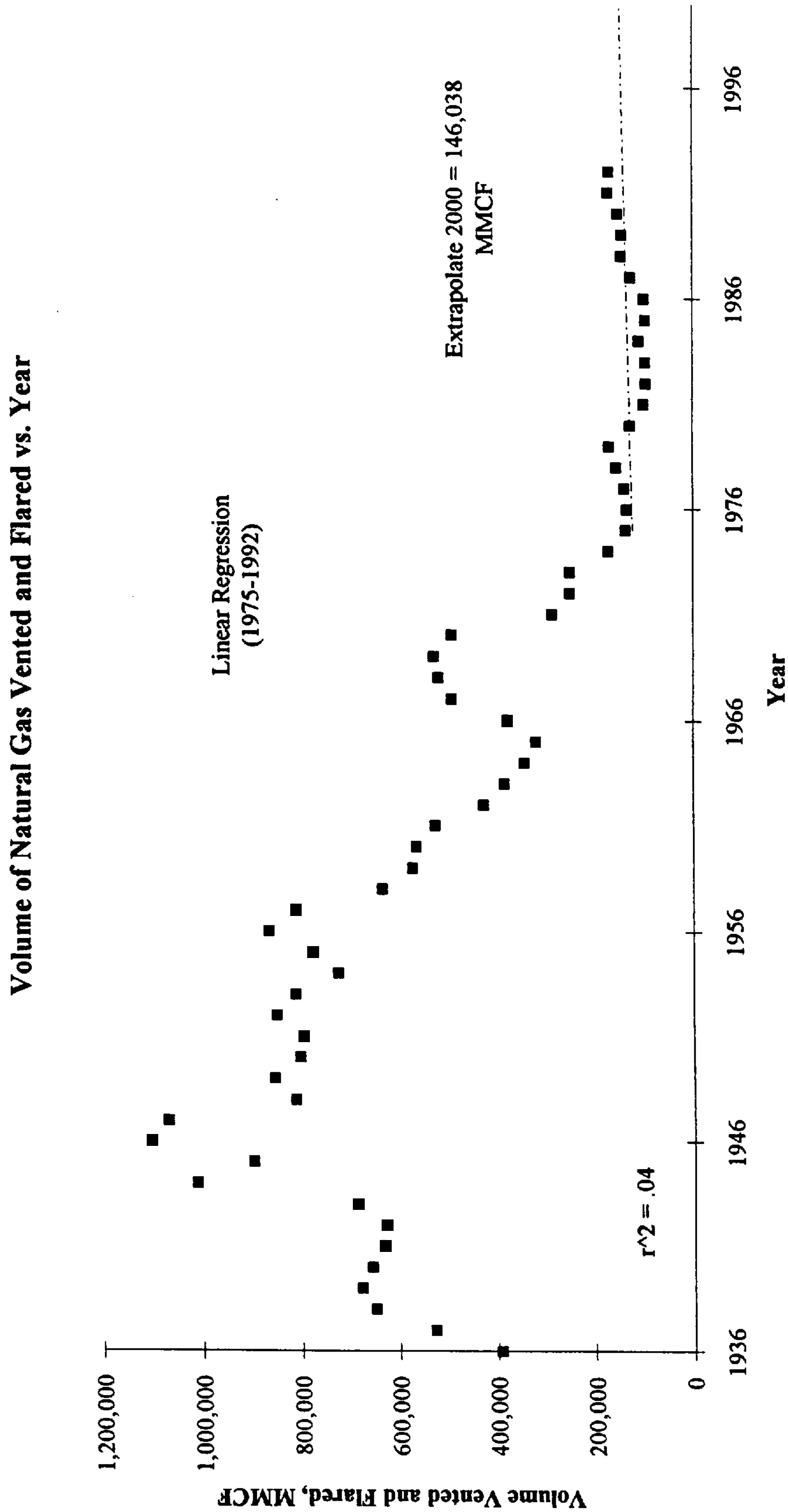
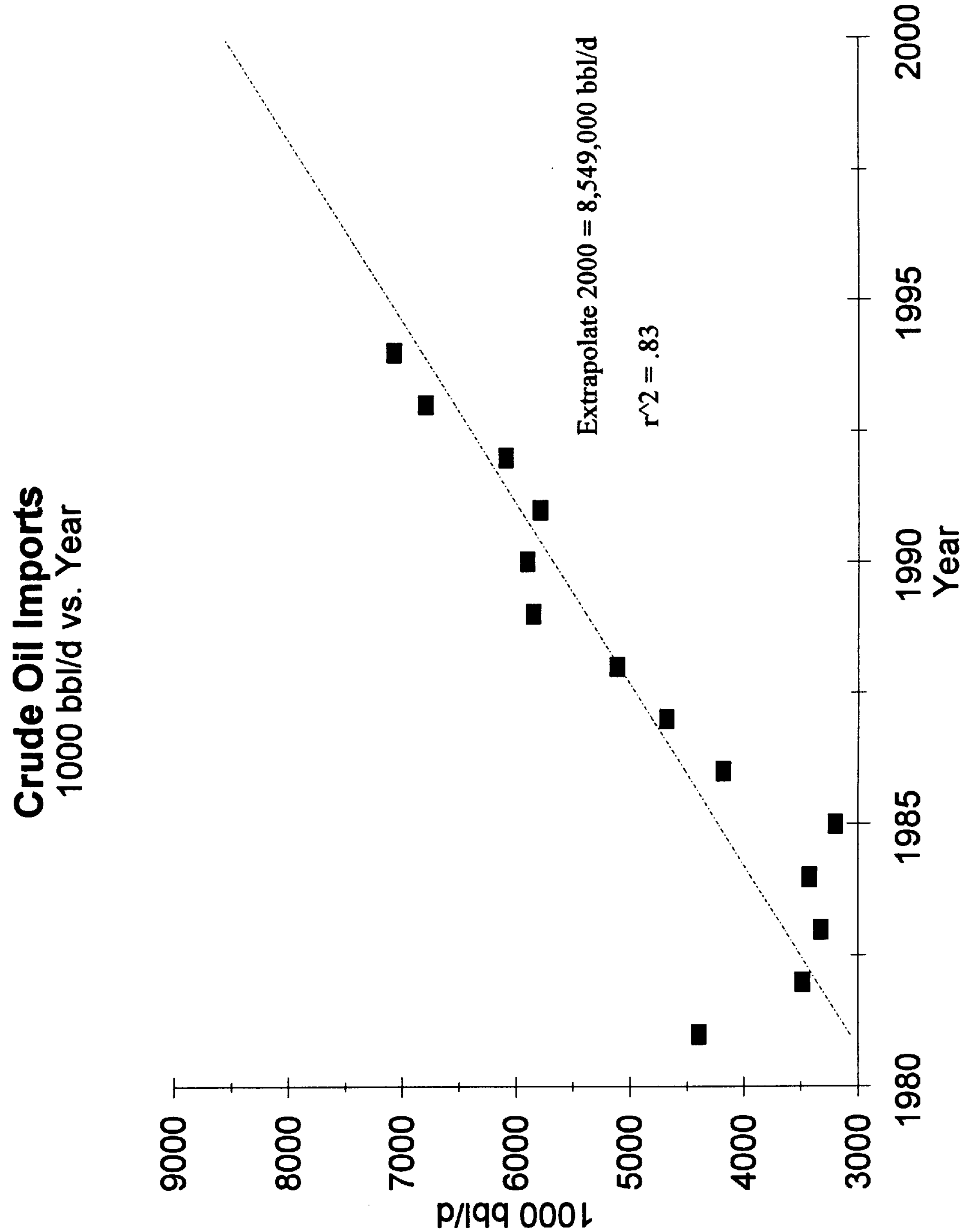
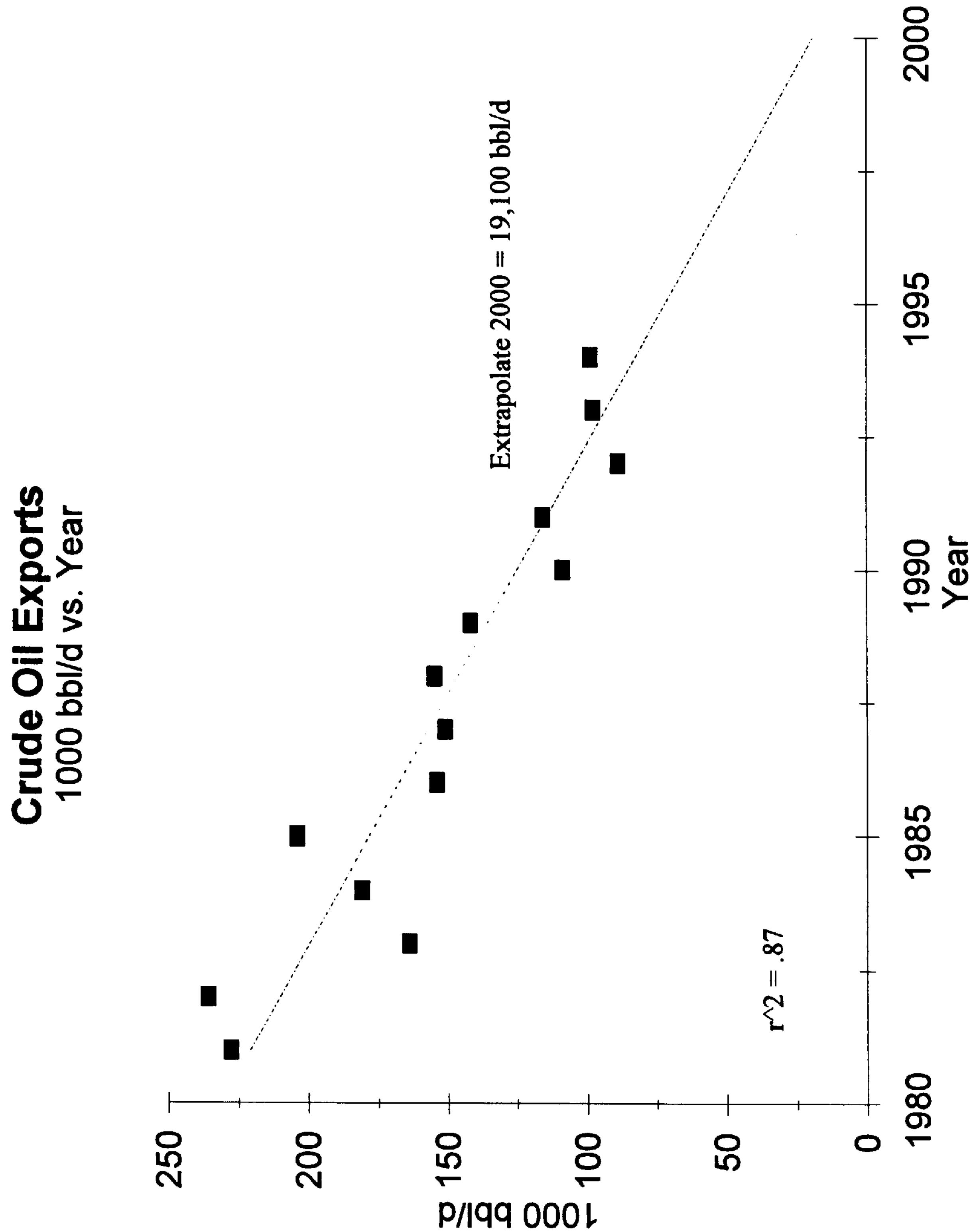
APPENDIX A

Supporting Figures for Section 4

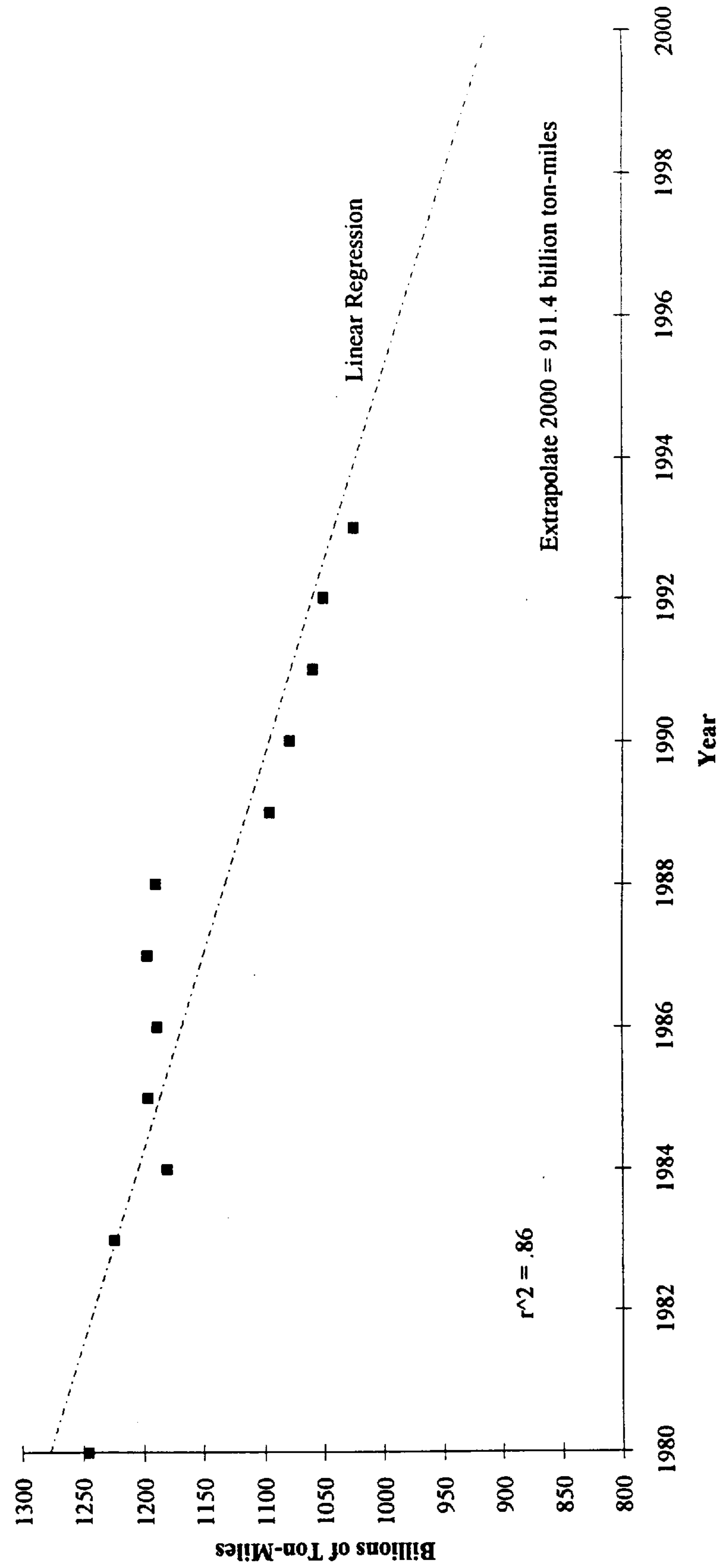

Total Producing Oil Wells vs. Year
Linear Regression
Extrapolate 2000 = 548,497 wells
r^2 = .78
Total Producing Oil Wells
700,000
600,000
500,000
400,000
Year
1989
1991
1993
1995
1997
1999

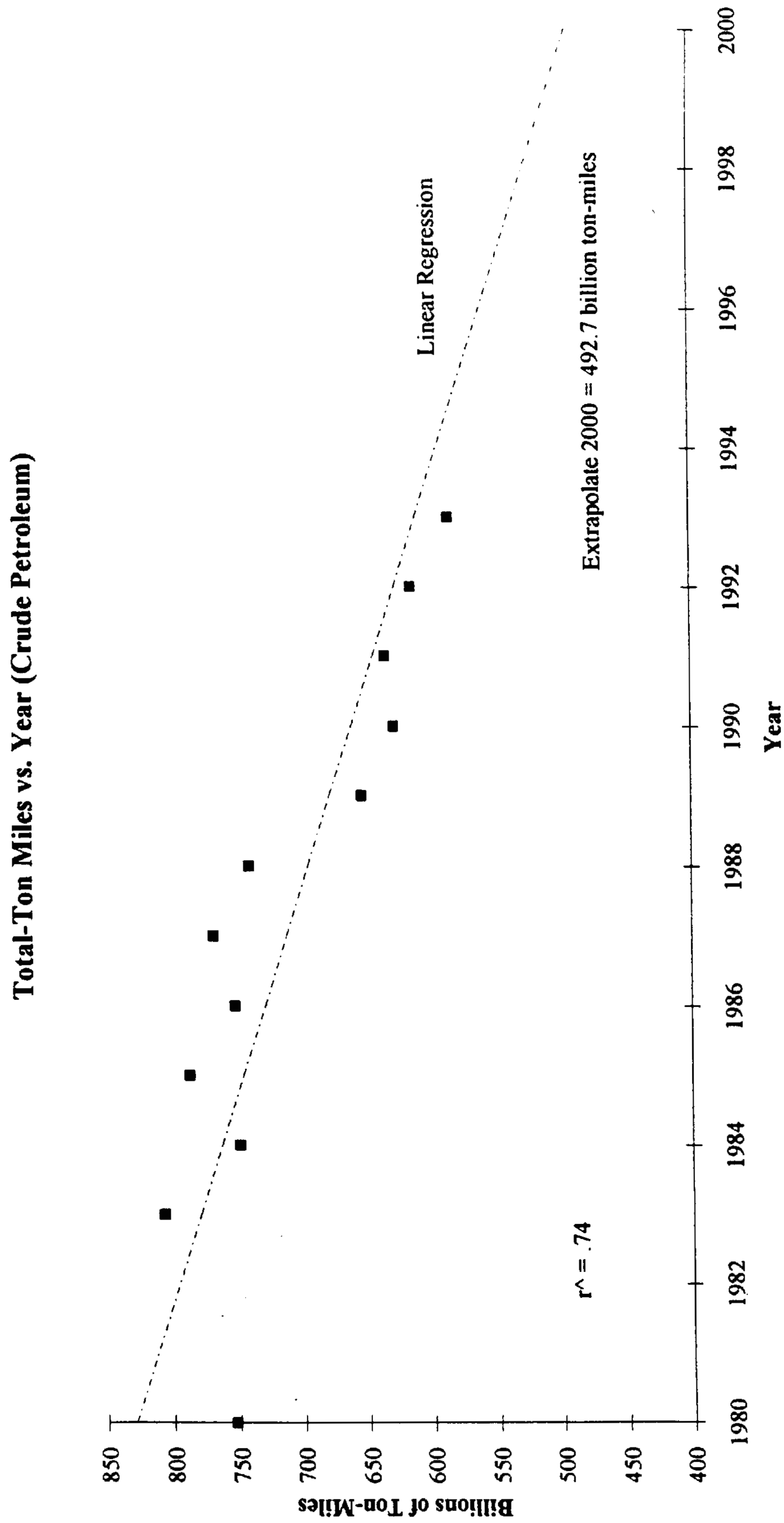

Volume of Natural Gas Vented and Flared vs. Year
Linear Regression
(1975-1992)
Extrapolate 2000 = 146,038
MMCF
r^2 = .04
Volume Vented and Flared, MMCF
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
1936
1946
1956
1966
1976
1986
1996
Year

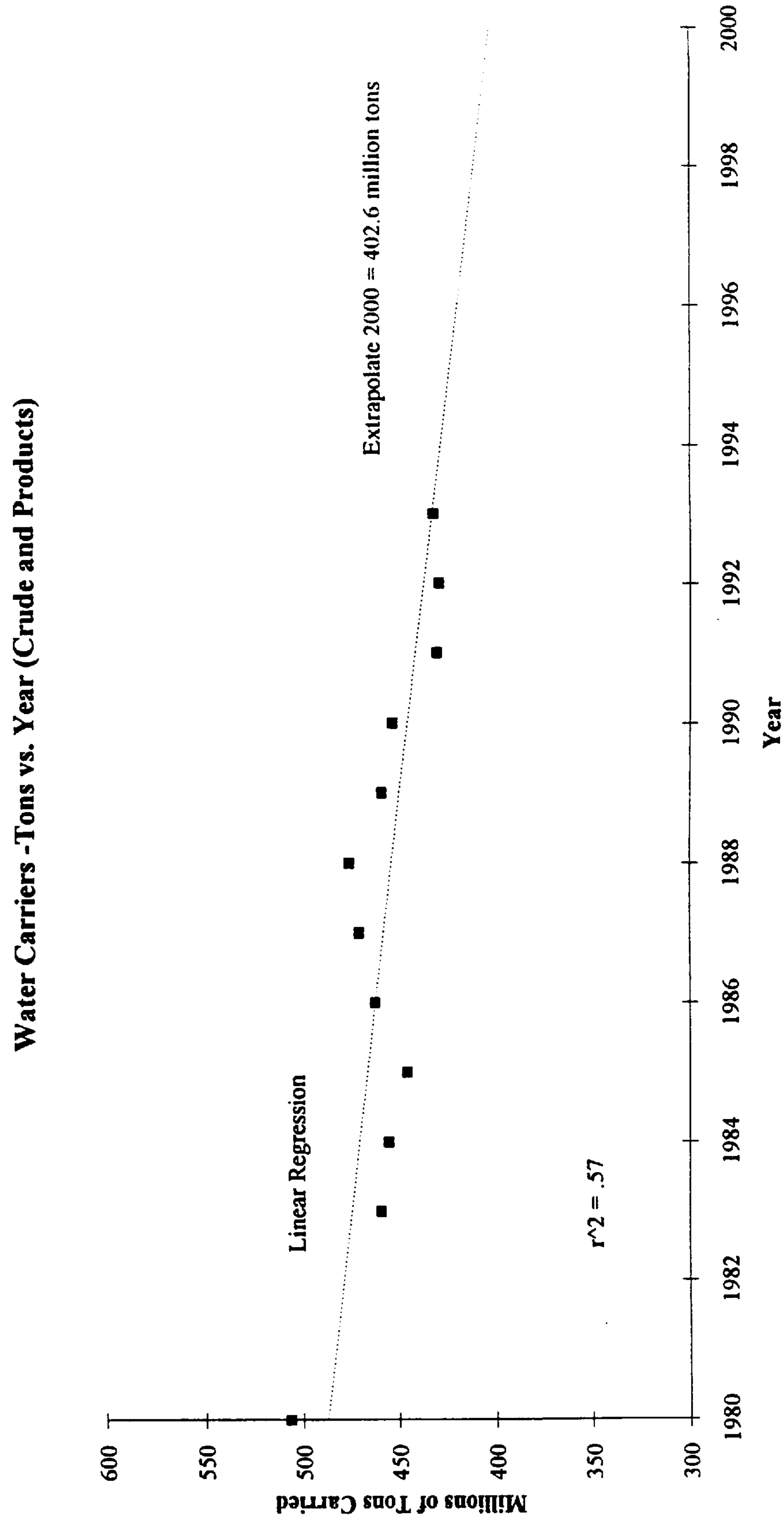

Crude Oil Imports
1000 bbl/d vs. Year
Extrapolate 2000 = 8,549,000 bbl/d
r^2 = .83
1000 bbl/d
9000
8000
7000
6000
5000
4000
3000
1980
1985
1990
1995
2000
Year

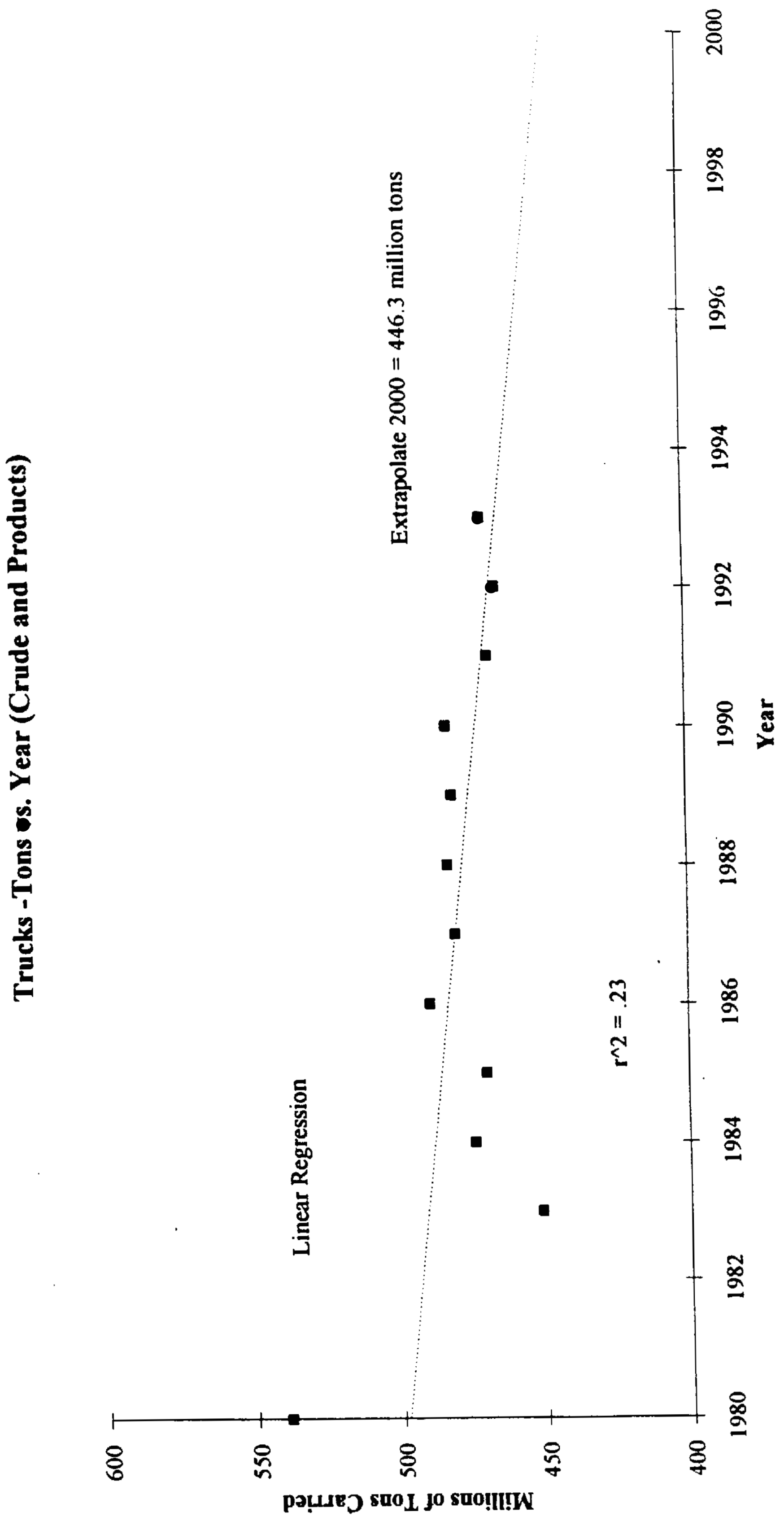

Crude Oil Exports
1000 bbl/d vs. Year
Extrapolate 2000 = 19,100 bbl/d
r^2 = .87
1000 bbl/d
0
50
100
150
200
250
1980
1985
1990
1995
2000
Year

Total-Ton Miles vs. Year (Crude and Products)

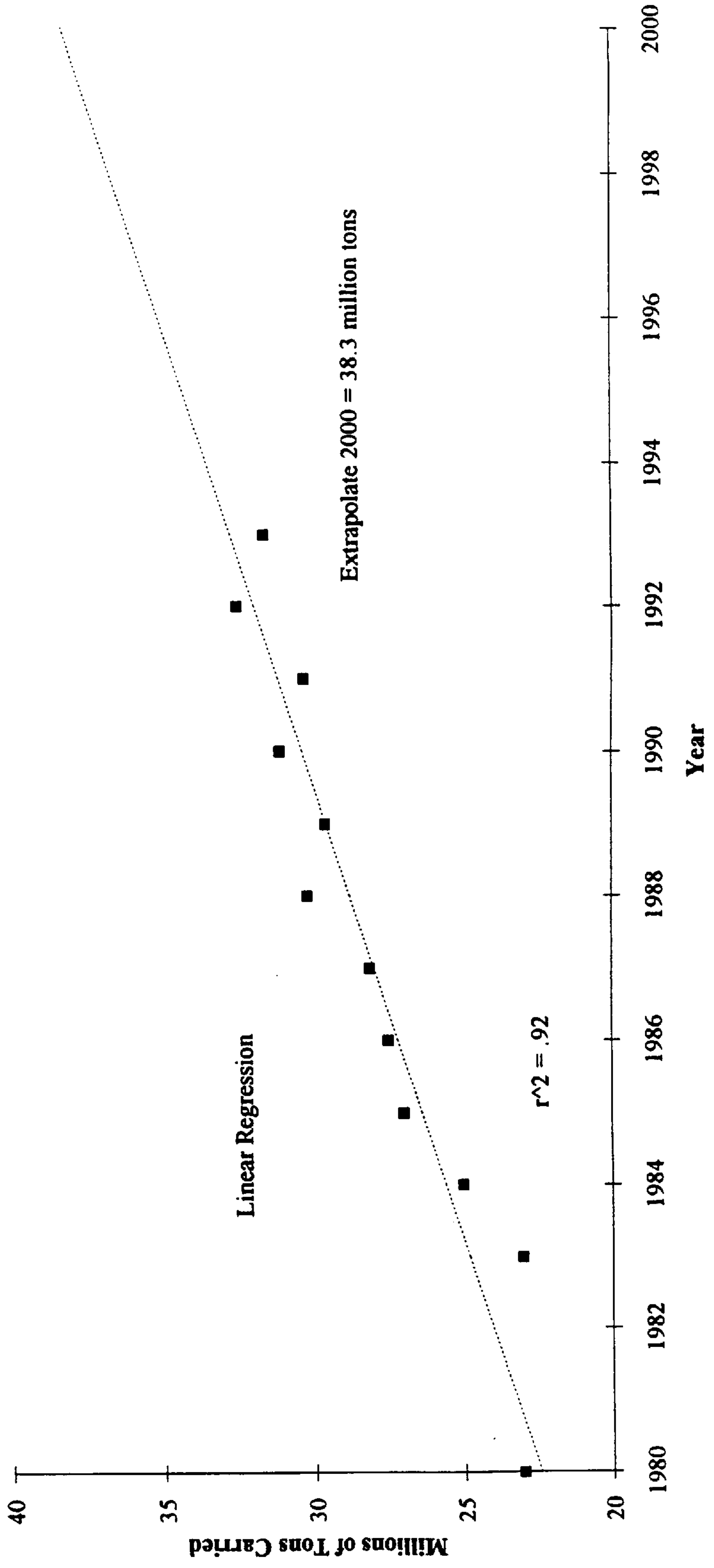


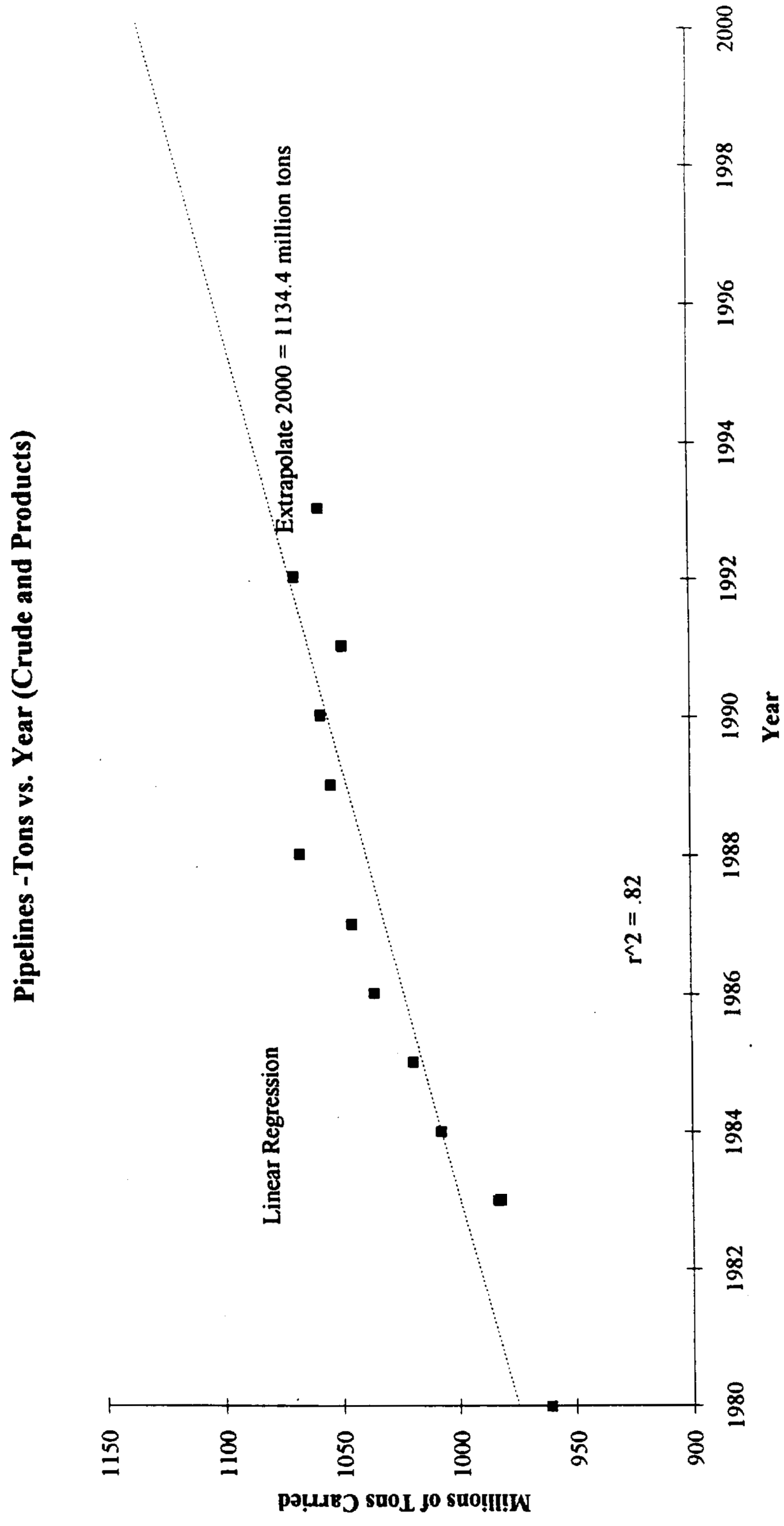

Total-Ton Miles vs. Year (Crude Petroleum)
Linear Regression
Extrapolate 2000 = 492.7 billion ton-miles
r^ = .74
Billions of Ton-Miles
850
800
750
700
650
600
550
500
450
400
Year
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000


Water Carriers -Tons vs. Year (Crude and Products)
Extrapolate 2000 = 402.6 million tons
Linear Regression
r^2 = .57
Millions of Tons Carried
600
550
500
450
400
350
300
Year
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000

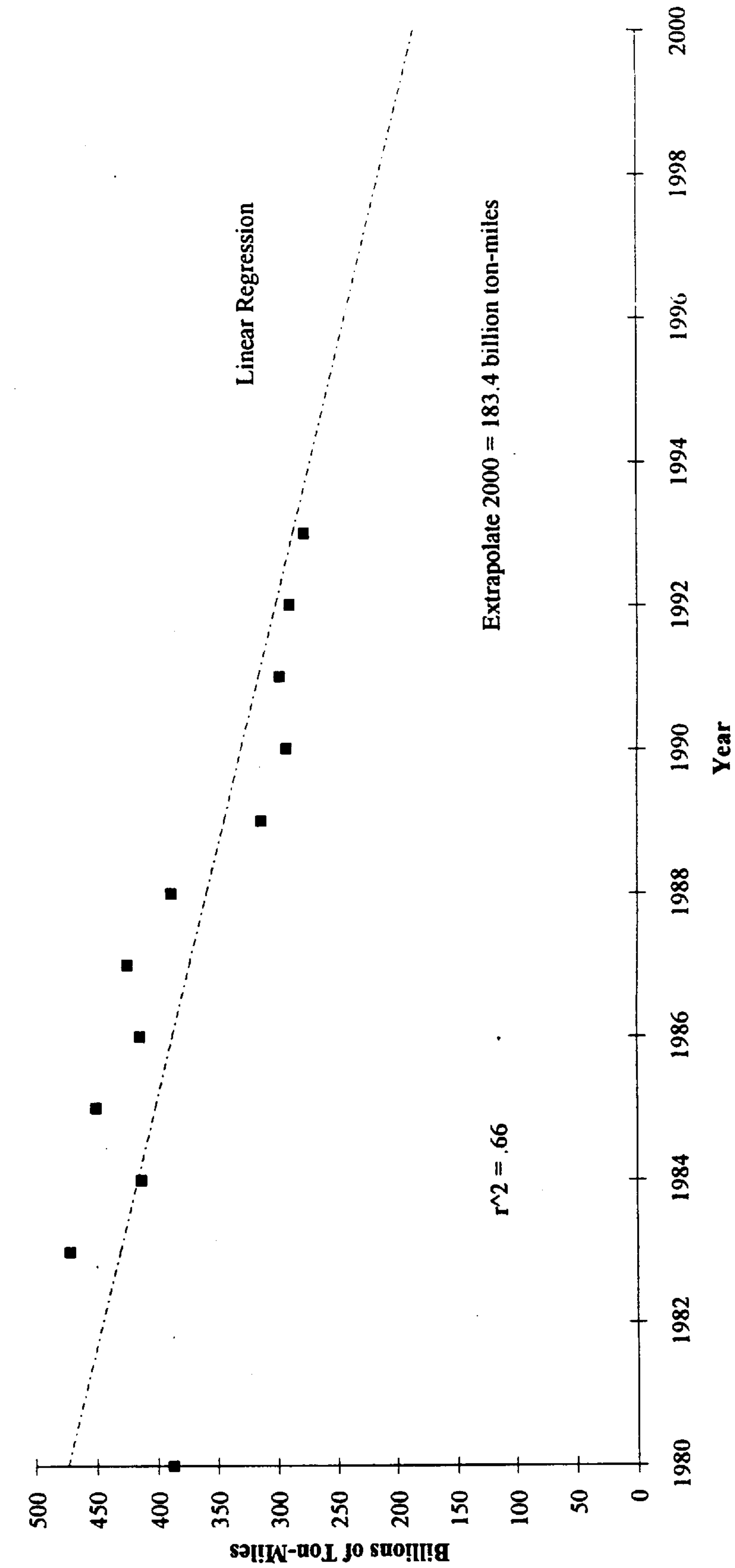

Trucks -Tons vs. Year (Crude and Products)
Linear Regression
Extrapolate 2000 = 446.3 million tons
r^2 = .23
Millions of Tons Carried
600
550
500
450
400
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
Year

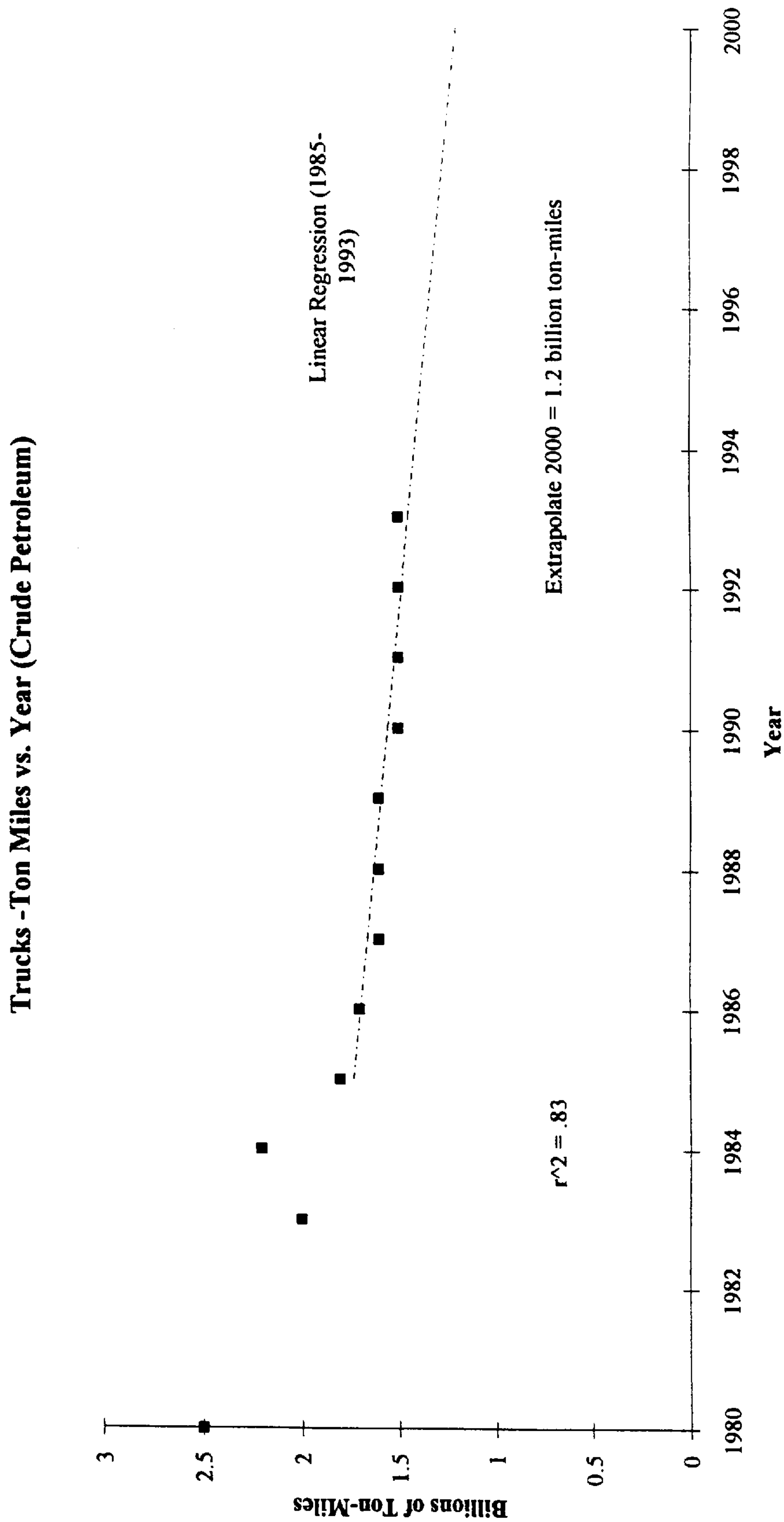
Railroads -Tons vs. Year (Crude and Products)

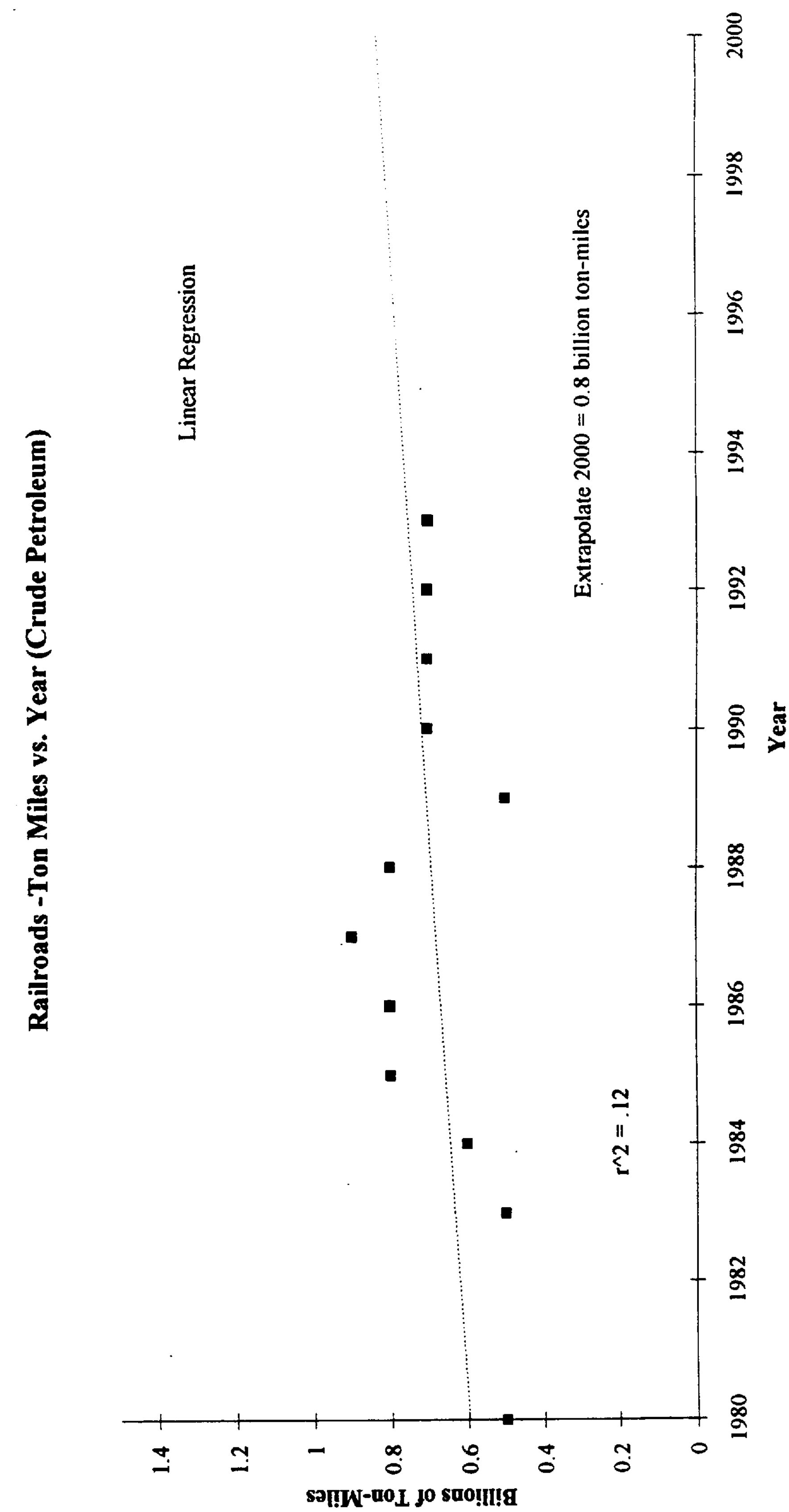


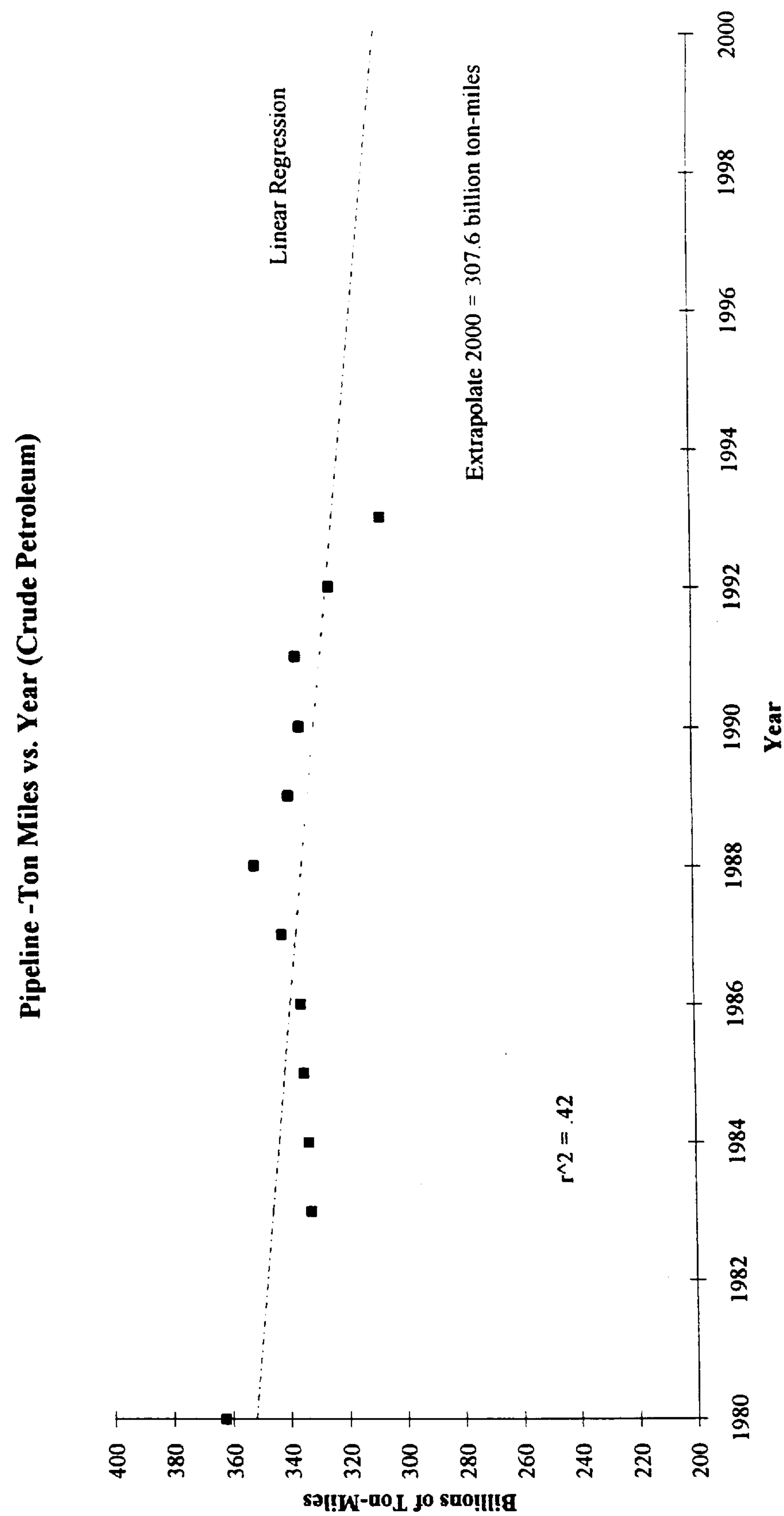

Pipelines -Tons vs. Year (Crude and Products)
Linear Regression
Extrapolate 2000 = 1134.4 million tons
r^2 = .82
Millions of Tons Carried
1150
1100
1050
1000
950
900
Year
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000

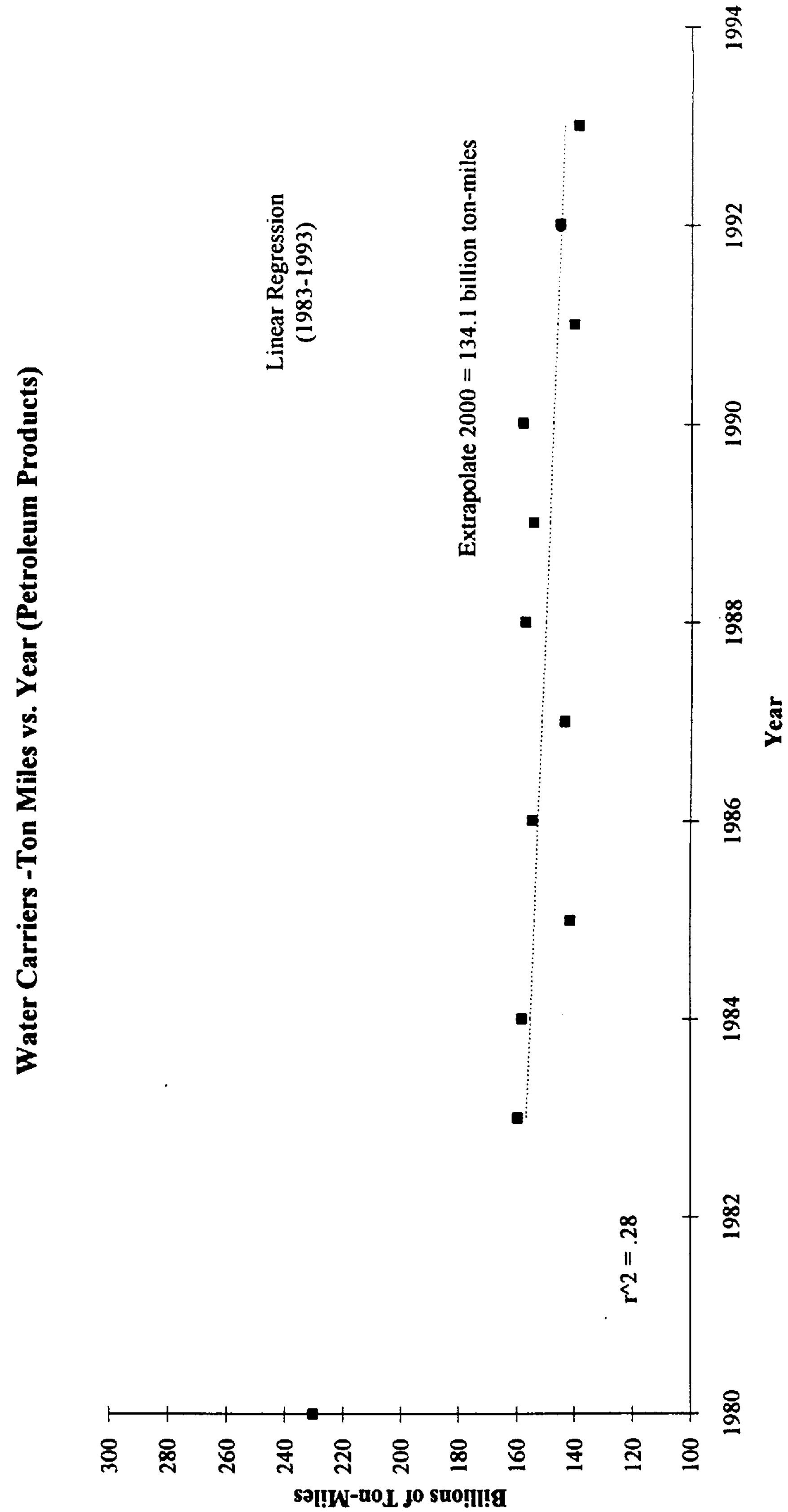
Water Carriers -Ton Miles vs. Year (Crude Petroleum)

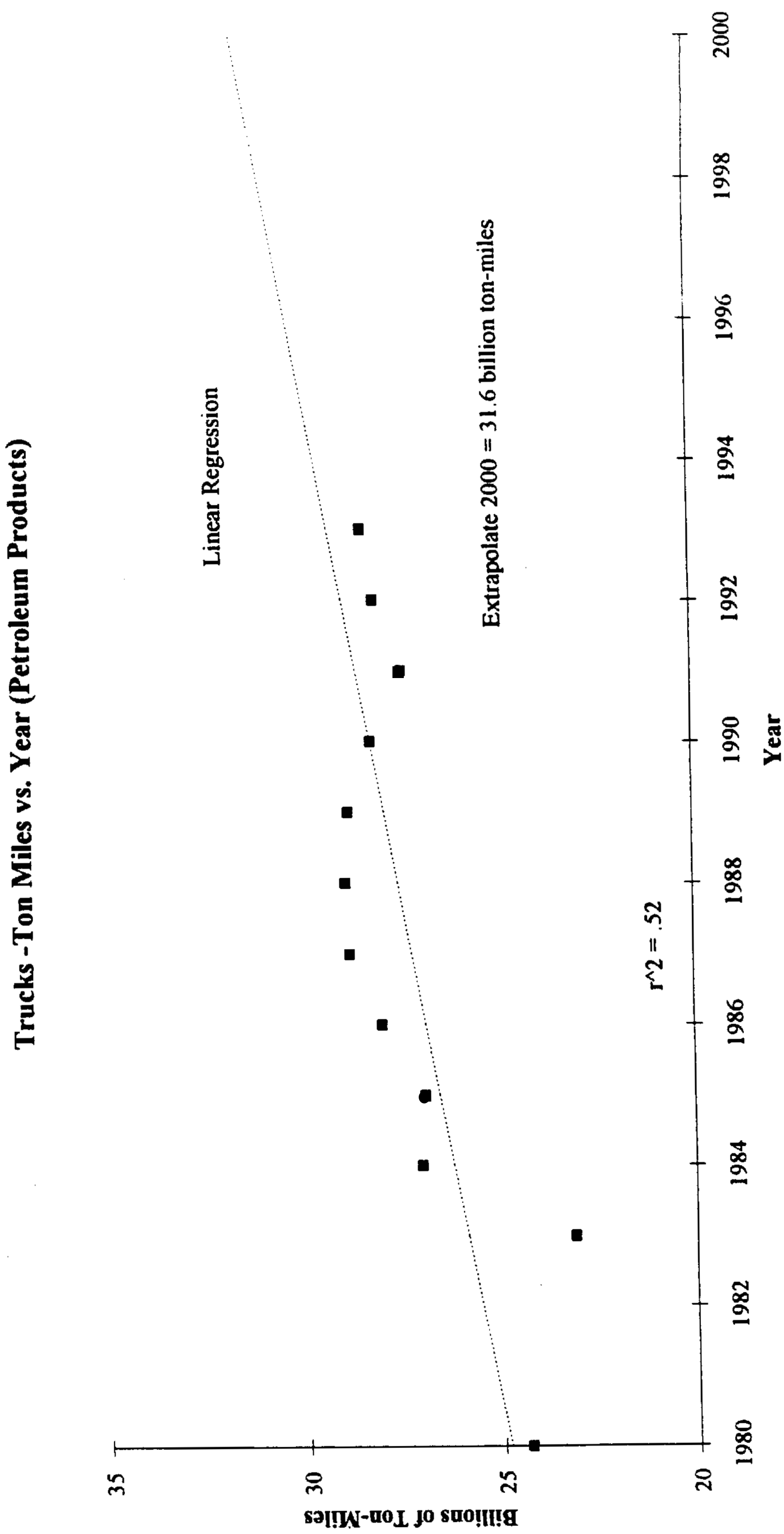


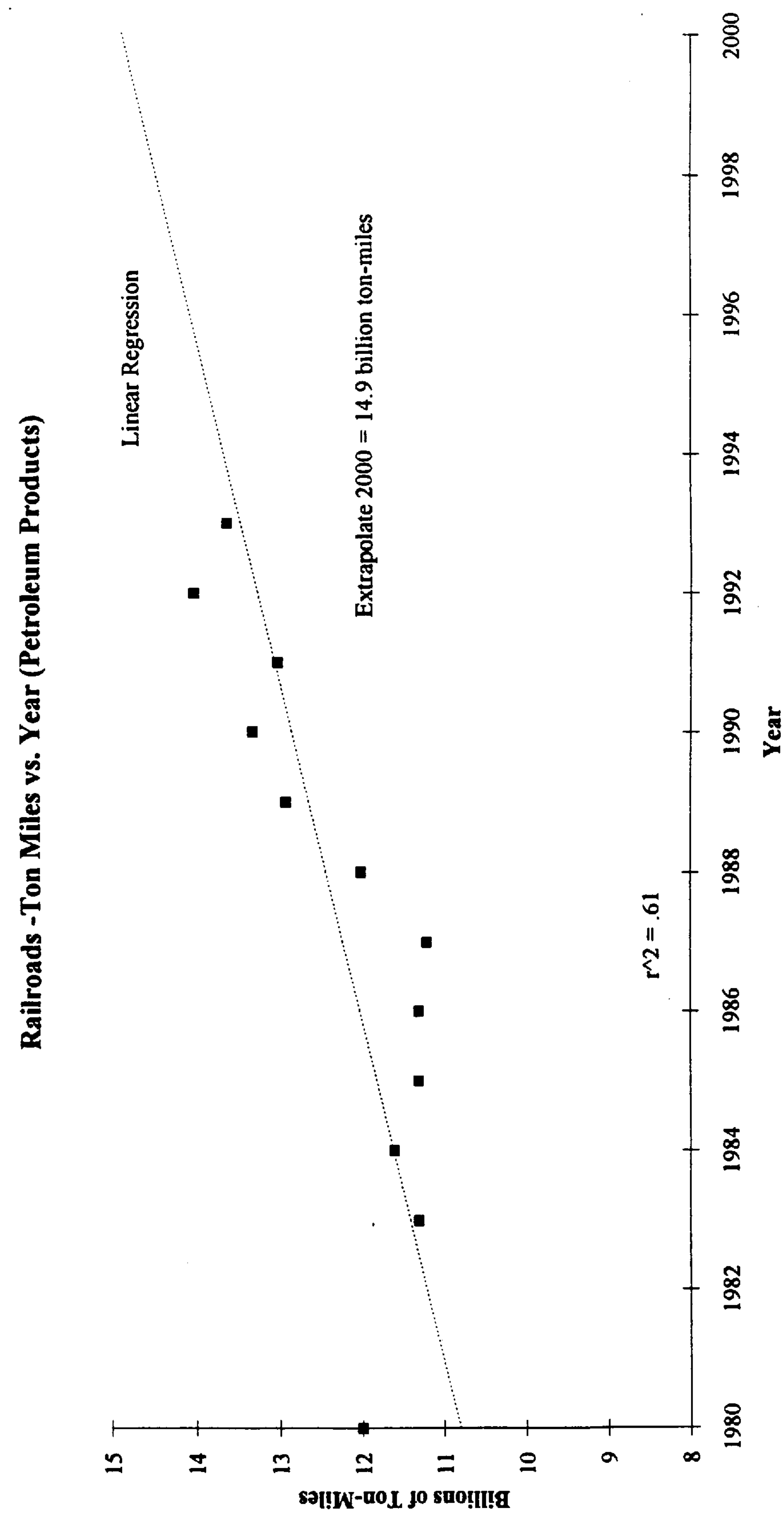

Trucks -Ton Miles vs. Year (Crude Petroleum)
Linear Regression (1985-1993)
Extrapolate 2000 = 1.2 billion ton-miles
r^2 = .83
Billions of Ton-Miles
Year
0
0.5
1
1.5
2
2.5
3
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000

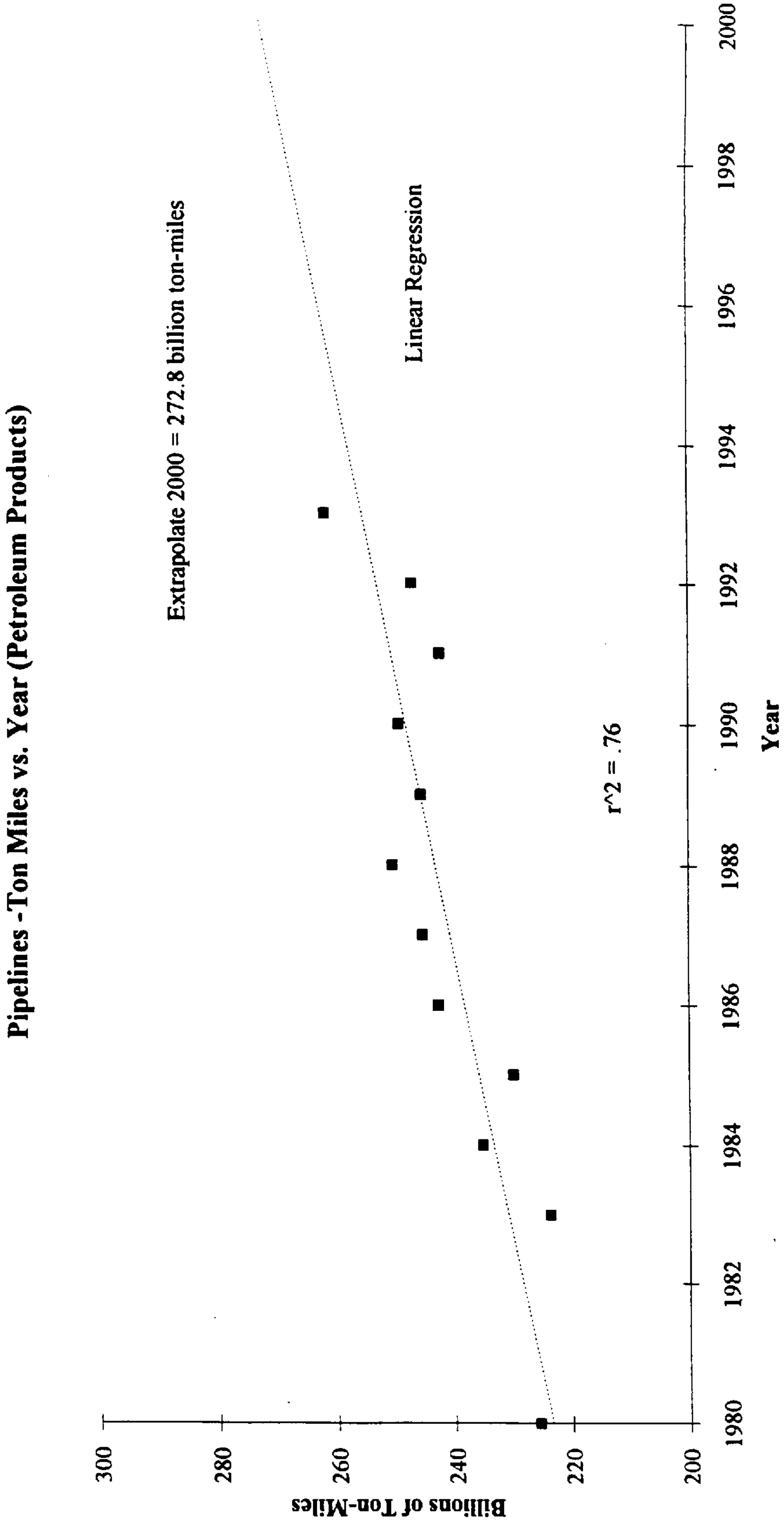

Railroads -Ton Miles vs. Year (Crude Petroleum)
Linear Regression
Extrapolate 2000 = 0.8 billion ton-miles
r^2 = .12
Billions of Ton-Miles
Year
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000


Pipeline -Ton Miles vs. Year (Crude Petroleum)
Linear Regression
Extrapolate 2000 = 307.6 billion ton-miles
r^2 = .42
Billions of Ton-Miles
Year
400
380
360
340
320
300
280
260
240
220
200
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000


Water Carriers -Ton Miles vs. Year (Petroleum Products)
Linear Regression
(1983-1993)
Extrapolate 2000 = 134.1 billion ton-miles
r^2 = .28
Billions of Ton-Miles
300
280
260
240
220
200
180
160
140
120
100
1980
1982
1984
1986
1988
1990
1992
1994
Year


Trucks - Ton Miles vs. Year (Petroleum Products)
Linear Regression
Extrapolate 2000 = 31.6 billion ton-miles
r^2 = .52
Billions of Ton-Miles
35
30
25
20
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
Year


Railroads -Ton Miles vs. Year (Petroleum Products)
Linear Regression
Extrapolate 2000 = 14.9 billion ton-miles
r^2 = .61
Year
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
Billions of Ton-Miles
8
9
10
11
12
13
14
15


Pipelines -Ton Miles vs. Year (Petroleum Products)
Extrapolate 2000 = 272.8 billion ton-miles
Linear Regression
r^2 = .76
Billions of Ton-Miles
Year
300
280
260
240
220
200
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000

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